Specification

Engineering Standard B-SPE-STD-010 UV Disinfection Systems

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(Refer Controlled Document in REX for Author, SME, Owner and Approver details)

Contents

1. Purpose

This document is part of a suite of Seqwater Engineering Standards which are in alignment with the Seqwater Quality Management System. Their purpose is to provide a consistent approach to the development, modification, and management of Seqwater infrastructure that is fit for purpose, economic over the life of the asset, and meets Seqwater's Work Health and Safety obligations.

This Standard Specification provides the Seqwater's minimum requirements for the design, selection, installation and validation of UV disinfection systems, and associated works used in drinking water treatment.

This document must be used in conjunction with the documents it references to assist in ensuring fit for purpose infrastructure. This Standard Specification is not intended to be relied on solely for design, supply, and installation works; advice from specialist engineers and/or manufacturers may be required on a case-by-case basis.

This Standard Specification does not cover:

- Feedwater pre-treatment processes (which may vary by application).
- UV based Advanced Oxidation Processes (AOPs). Note that if a UV based system is combined for disinfection and AOP, then this standard should be used to take credits for UV disinfection.
- Chemical dosing requirements.
- Sampling requirements.
- Maintenance practices.

2. Scope

This Standard Specification applies to all Seqwater employees, contractors, suppliers and consultants working for or on behalf of Seqwater unless otherwise stated. It applies to all new assets and to all existing assets undergoing refurbishment or modification. It must be used in conjunction with other relevant Seqwater Engineering Standards and project specific documents to define the technical requirements for infrastructure design and construction.

Where single or discrete components of an existing non-compliant system are to be replaced, refurbished or modified, this standard should not automatically be applied to the entire system retrospectively, however consideration should be given, in consultation with relevant stakeholders, to the extent of the application of the standard outside of the components requiring replacement, refurbishment or modification, to ensure safe, economic, and fit for purpose infrastructure.

Seqwater Engineering Standards detail Seqwater's minimum requirements and recommendations to provide infrastructure that will be fit for purpose, and safe to operate and maintain. However, compliance with these requirements and recommendations does not remove, and cannot be relied on as meeting, the designer's overarching responsibility for ensuring infrastructure designed is fit for purpose and safe to construct, operate, maintain, and demolish. The designer must exercise appropriate due diligence to identify and manage hazards so far as is reasonably practicable.

Designers must also ensure compliance with relevant Australian Legislation, Standards, Codes and Guidelines (including those produced by Water Services Association of Australia). Where no Australian Standard exists for a particular application, work must conform to the most current version of an industry accepted international standard.

Deviation from meeting the minimum requirements in this Standard Specification requires written agreement from Seqwater as per the deviation process detailed in Procedure X-PRO-STD-008 Asset Standards Management and Application. That process includes completion of an X-TMP-STD-022 Asset Standards Deviation Request Form and submission by the Seqwater Project Representative to the Seqwater Engineering Mailbox. Where noted in this Standard Specification that Seqwater approval, agreement, or acceptance shall/must be sought, such approval, agreement or acceptance must be gained through the Seqwater Asset Standard Deviation process, as outlined above.

Responsibility for ensuring compliance with Seqwater Engineering Standards lies with those engaged in the management and execution of design, construction, and modification of Seqwater infrastructure. This includes modifications to the functional design of the infrastructure including technical changes made which would extend an asset outside of its design operating envelope and/or approved operation and maintenance practices.

Any ambiguities or conflicts identified between specific requirements within this Standard and project documents, another Seqwater Engineering Standard or Australian Legislation, Standards, Codes or Guidelines, these must be brought to the attention of the Seqwater Document Owner, via the Engineering Mailbox, for clarification. Where it is proposed to proceed without meeting the requirements of this standard, agreement must be obtained via the Deviation Process, as outlined above.

Seqwater undertakes regular updates of its Engineering Standards. Before utilising this Engineering Standard, the complete list of Seqwater Engineering Standards should be reviewed to ensure currency and applicability of standards to be applied to the works. These can be accessed on the Waternet Engineering and Asset Standards page. Instructions for downloading Standards are provided on the Waternet Engineering and Asset Standards page.

3. General Requirements

This section provides a number of general requirements for the design and installation of a UV system and modifications to an existing system with reference to other applicable standards.

3.1. Safety in Design

In order to incorporate safety in design, Seqwater has a number of standards that shall be used in the design and review of new assets and installations:

- X-PRO-STD-009 Engineering Design, Construction, Operation and Maintenance
- X-PRO-STD-013 Engineering Technical Hazard Study

These standards include discussion of the various risk assessments/reviews, studies, and management systems that must be in place/demonstrated and used to satisfy legislative and Seqwater requirements.

All designs and installations shall ensure due consideration of reliability, accessibility, maintainability, constructability and operability are taken. This shall be demonstrated through auditable design documentation, reviews, communication, meetings, processes/procedures etc.

Design decisions and residual risks in design shall be supported, reviewed and accepted in accordance with FRA-00014 Enterprise Risk Management Framework.

3.2. Engineering Units

Where not specified in this document, equipment and instrument units shall be in accordance with the requirements of *I-SPE-STD-013 Control Systems Design and Construction.*

3.3. Design Life

Table 1 provides the expected design life of major UV system components which represents expected duration of operation. However, guaranteed life which incorporates the risk and variability of material quality and operating conditions may be different from that of the expected design life. Equipment vendors must be consulted for details specific to their equipment including guaranteed life.

Table 1 Expected Design life specifically related to UV System assets.

Asset Class	Design Life
Ballasts	5 to 7 years
Lamp Sleeves	3 to 5 years
UV Lamps	12,000 hrs for mercury Low Pressure (LP) lamps and 10,000 hrs for mercury Medium Pressure (MP) lamps
UV Intensity Sensor	3 to 5 years
Cleaning System	3 to 5 years

Seqwater Standard for General Mechanical M-SPE-STD-001 needs to be referred for the design life of valves, pumps, pipework and protective coatings.

3.4. Site Conditions

Site Conditions is intended to mean any of the ambient conditions, process conditions, ground conditions and operating conditions that may be reasonably expected to occur during normal operation.

Ambient conditions for mechanical, electrical and control equipment shall be specified from the following documents:

a. E-SPE-STD-001 Electrical Design and Construction

b. I-SPE-STD-013 Control System Design and Construction

c. M-SPE-STD-001 General Mechanical Specification

Design and construction shall allow all assets to operate continuously and uninterrupted between the minimum and maximum Site Conditions specified.

If not defined by Seqwater, Ambient Conditions for design and construction of process equipment shall be determined by the Designer or Contractor and submitted to Seqwater for approval.

3.5. Materials

UV reactor materials selected in design shall be appropriate to the applications for which they are intended. Guidance should be sought from the following for the design of a UV system as a minimum:

a. Relevant Australian and industry standards and specifications for the material(s) selected.

b. Vendor and supplier recommendations and experience

c. M-SPE-STD-001 General Mechanical

d. M-SPE-STD-002 Fixed Platforms, Walkways, Stairways and Ladders.

e. M-SPE-STD-004 Protective Coatings

f. M-SPE-STD-013 Chemical Dosing Piping

g. D-SPE-STD-001 Water Supply Networks Planning, Design and Construction (Seqwater Supplementary Manual to WSAA, Water Supply Code of Australia WSA03-2011).

Where stainless steel is used, passivation and pickling must be carried out correctly in accordance with ASTM A380 to protect fabricated welded areas.

Materials used in equipment, piping, coatings, joining and others which may come in contact with drinking water must have an appropriate certification to AS/NZS 4020. Refer to potable water compatibility section of *M-SPE-STD-001 General Mechanical* for further details.

3.6. Equipment Selection

In general, this standard specification does not specify the type and manufacturer of equipment (UV reactors, pumps, valves, instruments etc.) for a design. Where not specified, requirements shall be sought from the following as a minimum:

a. X-LST-STD-001 Seqwater Preferred Equipment

b. M-SPE-STD-009 Flow Meters

c. M-SPE-STD-001 General Mechanical

d. I-LST-STD-001 Control System Prescribed Equipment

e. Improved energy performance of new equipment shall be considered in the equipment selection process as specified in the following documents:

f. PLN-00452 Seqwater Corporate Energy Strategy

g. E-GDE-STD-001 Energy Metering and Monitoring Guideline

h. E-MAN-STD-001 Energy Efficiency Manual.

3.7. Colour and Coatings

Buildings, enclosures and shelters, pipes, tanks, fittings, fixtures, equipment and surfaces shall be coloured / coated in accordance with:

a. M-SPE-STD-001 General Mechanical

b. M-SPE-STD-004 Protective Coatings

c. AS 2312.1 Guide to the protection of structural steel against atmospheric corrosion by the use of protective coatings – Paint coatings

d. AS 2312.2 Guide to the protection of structural steel against atmospheric corrosion by the use of protective coatings – Hot dip galvanizing

e. AS1345 Identification of the contents of pipes, conduits and ducts

f. Other relevant legislation and Australian Standards, especially those referenced in the above documents.

3.8. Pipework, Valves, Fittings and Isolation

All pipework and fittings, isolation of piping systems, valves and actuators shall comply with the requirements of the following Seqwater Standard Specifications, and the relevant industry and Australian standards referenced within:

a. M-SPE-STD- 001 General Mechanical

b. M-SPE-STD-003 Valves for Water Applications.

3.9. Civil Works

Civil works shall comply with the requirements of D-SPE-STD-001 Water Supply Network Planning, Design and Construction (Seqwater Supplementary Manual to WSAA, Water Supply Code of Australia WSA03-2011), and relevant Seqwater, Australian and industry Standards, Specifications and Codes.

All concrete shall be suitably finished, and the coating requirement shall be applied in accordance with M-SPE-*STD-004 Protective Coatings*.

3.10. Mechanical and Structural Works

Mechanical and metal structural design, construction and equipment selection shall be completed in accordance with the legislative requirements, Seqwater's specifications, Australian and Industry Codes and Specifications.

Refer to M-SPE-STD-001 General Mechanical for further guidance.

3.11. Electrical Works and Lighting

All electrical works and lighting equipment design, construction, installation and testing shall comply with the requirements of *E-SPE-STD-001 Electrical Design and Construction,* the standards referenced within, and relevant Australian and industry Standards, Specifications and Codes.

Section 5.17 of this document shall be referred for some specific requirements of UV reactor power supplies.

Lighting, of sufficient illuminance, must be provided for all markings, signs, instruments, valves, fittings, connections, reactors, roads, rooms and buildings related to UV disinfection systems. Lighting luminance specification shall be as per the requirement of *E-SPE-STD-001 Electrical Design and applicable part of AS/NZS 1680 series.*

3.12. Instrumentation Works

Instrumentation shall comply with the requirements of *E-SPE-STD-001 Electrical Design and* Construction, *I-SPE-STD-015 Instrumentation, other* Seqwater, Australian and industry codes and standards. In addition, instrumentation works must meet the following general requirements and other requirements specified in this standard.

a. Transmitters and control circuits shall comply with the voltage requirements of E-SPE-STD-001 Electrical Design and Construction.
b. Safety devices or switches used for equipment protection, critical process safety, protection against environment release, or personal safety shall be hardwired and fail-safe in accordance with the requirements of I-SPE-STD-013 Control Systems Design and Construction.
c. Flow meters shall comply with the requirements of M-SPE-STD-009 Flow Meters and X-LST-STD-001 Seqwater Preferred Equipment for the selection and installation. Flow switches may be used as a secondary means of flow identification.
d. Indicators shall comply with the requirements of the Instrumentation Indicators section of E-SPE-STD-001.
e. Displays shall be digital and suitably weatherproof to the Site Conditions and shielded to prevent glare.
f. Refer to Section 5.10 for specific instrumentation requirements associated with UV reactors.

3.13. Telemetry and Control

Control systems shall comply with the requirements of the standards listed below, the requirements of this standard, and relevant Australian and industry Standards, Specifications and Codes:

a. I-SPE-STD-009 Control Systems Architecture
b. I-SPE-STD-013 Control Systems Design and Construction
c. Standards noted above are the key standards relevant to this section, but the standards noted within these key standards shall also apply and must be considered as part of the design.
d. Some specific details of UV system control requirements, process control narrative and interface requirement between SCADA and vendor package are provided in Section 6 herein.

3.14. Cyber Security

While the UV system shall be supplied as a package unit, the vendor shall comply with Seqwater cyber security requirements, as specified in the SPE-00502 Control Systems Cyber Security Standard.

The vendor shall provide sufficient information as requested by Seqwater to allow assessment of cyber security risks.

3.15. Signage, Tagging, Marking and Labelling

All equipment, instrumentation, and pipework shall be numbered and labelled, and include nameplates as required in accordance with:

a. M-SPE-STD-001 General Mechanical

b. E-SPE-STD-001 Electrical Design and Construction

c. I-SPE-STD-010 Control System Tag Naming

d. X-PRO-STD-006 Equipment Numbering and Naming Convention .

4. Overview of UV Disinfection Systems

This section provides background on ultraviolet electromagnetic radiation (herein referred to as UV) disinfection systems. This section is not intended to provide design guidance or advice; however, this standard does require the application of some of the materials provided here.

For design guidance refer to Sections 5, 6 and 7.

Ultraviolet (UV) disinfection is a form of non-chemical disinfection by exposure of water to UV electromagnetic radiation. It is a proven means of pathogenic inactivation of water sources and, unlike typical chemical disinfection, is effective in providing protection against *Legionella bacteria and* protozoans such as *Cryptosporidium and Giardia*.

UV wavelengths penetrate the outer membrane of organism cells, passing through the cell body. When absorbed by the cells UV wavelengths result in damage to the genetic material (DNA) thereby inhibiting the organism's ability to grow and reproduce. The disinfection mechanism of UV light differs considerably from chlorine or ozone chemical disinfection which inactivate microorganisms by destroying cellular structures and interfering with their metabolism, and thus obstructing their growth.

UV dose is a function of the UV intensity (measured in mW/cm^2) and duration (given in seconds) to which a pathogen is exposed.[1] UV Dose is expressed in the units of $mW.s/cm^2$, which is generally simplified to mJ/cm^2.

4.1. UV Light and Disinfection

UV forms a small component of the total electromagnetic radiation spectrum; just as visible light does. It's span of the total electromagnetic spectrum is depicted in Figure 1.

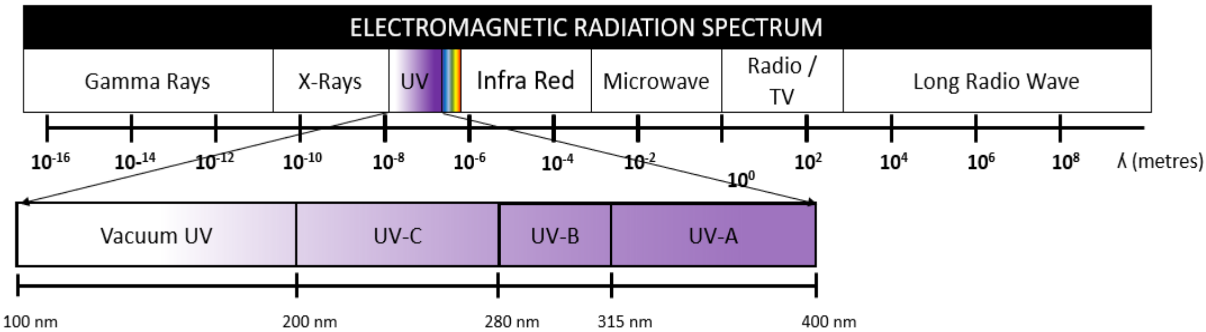

Figure 1 Diagram showing the wavelength band of UV energy across the full electromagnetic spectrum.

There are four main classes of UV radiation that may be categorised by their wavelengths: UV-A (315-400 nm), UV-B (280-315 nm), UV-C (200-280 nm), and vacuum UV (100-200 nm).

[1] Scientific literature may refer to dose as 'fluence', Fluence is the time integral value of fluence rate – fluence rate is the UV intensity per unit area per time. Fluence would therefore be measured in mJ/cm^2 while fluence rate would be measured in mW/cm^2.

Germicidal effects are most pronounced between the wavelengths of 200-280 nm, corresponding to UV-C radiation. UV radiation has been shown to damage cellular proteins and nucleic acids and prevent replication in pathogens. By preventing replication, a pathogen's ability to infect a host is removed.

Historically, the most common technology that generates UV light with a peak wavelength of 253.7 nm is low-pressure mercury vapour lamps. As a result, a wavelength of 254 nm has become the industry standard for measurement of pathogen inactivation. Medium pressure mercury lamps tend to produce a wider range of wavelengths between 200-280 nm.

While pathogen cells are damaged by exposure to UV light, the energy provided in most disinfection systems does not typically kill the pathogen and cell metabolism continues to function. To prevent cell metabolism, a UV dose orders of magnitude greater than that to prevent cell replication is required. This document therefore refers to UV disinfection as providing 'inactivation' of pathogens, rather than killing, destruction or elimination.

4.1.1. UV Transmittance

UV transmittance (UVT) refers to the percentage (%) of UV wavelengths that pass through a medium (water), in a straight line from the energy source, after accounting for absorbance and scattering within the medium. This is important in UV disinfection as it defines the portion of the emitted energy that will be available to actually carry out disinfection.

UV absorbance is the logarithm of the ratio of the incident UV intensity to the measured intensity after transmission through a medium – see Equation 2. It defines the portion of UV wavelengths that are absorbed by the constituents in a medium (e.g. molecules, pathogens etc.).

UVT is standardised over a specific distance (typically 1cm) i.e. the emitted UV intensity is known, and the UV intensity at the specific distance from the source is measured. As UV light is often present over a range of wavelengths, the measurement of UVT is typically standardised at a measurement of 254 nm for consistency and simplicity, and this standardisation shall be assumed in this document when discussing UVT.

The below equations provide the relation between UV transmittance and absorbance.

$$T\ (\%) = 100 * \frac{I}{I_0} \qquad (1)$$

$$A = \log\left(\frac{I_0}{I}\right) \qquad (2)$$

And therefore,

$$A = -\log\left(\frac{T(\%)}{100}\right) \qquad (3)$$

Or $T(\%) = 100 \times 10^{-A}$ (4)

Where:

A = Absorbance of electromagnetic radiation through a medium at a specified wavelength (e.g. 254 nm) and at a specified distance (e.g. 1 cm)

T = Transmittance (as fraction of the incident radiation) through a medium at a specified wavelength (e.g. 254 nm) and at a specified distance (e.g. 1 cm)

I_0 = Electromagnetic intensity generated from a source (mW/cm^2)

I = Electromagnetic intensity measured through a medium (i.e. water) at a specified distance (e.g. 1 cm) (mW/cm^2)

4.2. Log Reduction Value (LRV)

Log Reduction Value (LRV) is a general term used to refer to the extent of removal of a pathogen that is achieved in a treatment process. It is an order of magnitude representation of the reduction in concentration achieved through a treatment process. It is calculated as follows:

$$LRV = log_{10}\left(\frac{N_0}{N}\right) \quad (5)$$

Where:

N_0 = pathogen concentration into a process before exposure of UV light

N = pathogen concentration out of a process after exposure of UV light

I.e. A 90% reduction in concentration is equivalent to a 1.0 log reduction.

A 99% reduction is equivalent to a 2.0 log reduction.

A 99.9% reduction is equivalent to a 3.0 log reduction; and so on.

4.3. Required UV Dose and Design Validation

Each pathogen displays a varying degree of resistance to UV induced degradation, and therefore requires a different 'dose' for inactivation. UV dose is a product of the UV intensity (UVI) the pathogen is exposed to (in mW/cm^2) and time over which a pathogen is exposed (in seconds). The resulting dose is given in mJ/cm^2.

i.e. $$Dose\left(\frac{mJ}{cm^2}\right) = UVI\left(\frac{mW}{cm^2}\right) \times t(s) \quad (6)$$

For a given pathogen, increasing the dose will, in general, result in an increase in the LRV achieved for that pathogen. The relationship between dose and pathogen inactivation is not linear, and for a given pathogen, a curve of this relationship may be experimentally derived.

A summary of the LRV for *Cryptosporidium*, *Giardia*, and viruses and the required UV dose is provided in Table 2 as reported by US EPA.

Table 2 Summary of required UV dose to achieve LRV based on US EPA, 40 CFR 141.720 (d)(1).

Target Pathogen	Log Reduction Value							
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Cryptosporidium	1.6	2.5	3.9	5.8	8.5	12	15	22
Giardia	1.5	2.1	3.0	5.2	7.7	11	15	22
Viruses[2]	39	58	79	100	121	143	163	186
	All values in mJ/cm^2							

The required inactivation UV doses for Cryptosporidium and Giardia are much lower than those needed for viruses as shown in Table 2. Bacteria are also notably more sensitive to UV damage than are viruses, and therefore research has tended to focus on viral reactivity (US EPA, 2006).

[2] Viruses is a generic term to cover the worst case of UV resistant viruses that might be expected to be present in water sources.

UV reactors need validation to demonstrate that they can achieve the required UV dose and the validation protocol discussed in Section 4.4 below. The validated dose for a reactor must be greater than or equal to the required dose for the required LRV for a target pathogen. The validated dose is obtained by dividing the calculated dose by a validation factor.

Calculated dose is the Reduction Equivalent Dose (RED) and the significance of RED is described in Section 4.3.1 below. RED is calculated using the dose monitoring equation developed during the validation testing. The validation factor accounts for key uncertainties from validation testing. The relationships of Required Dose, Validation Dose, Validation Factor and RED are given below:

$$Validated\ Dose = \frac{RED}{Validation\ Factor} \tag{7}$$

$$Validated\ Dose\ \geq\ Required\ Dose \tag{8}$$

Where, Validation Dose, Required Dose and RED have the same units of mJ/cm^2, and the Validation Factor is unitless.

4.3.1. Reduction Equivalent Dose (RED)

The RED is a way of stating the standardised dose received by the bulk fluid. It relates the effective performance of the UV reactor and the dose delivered to the bulk microorganisms with a laboratory derived dose value needed to inactivate a specific pathogen.

When a UV disinfection system is installed, the precise dose received by any microorganism cannot be directly measured. Given the uncontrolled nature of the reactor environment, each microorganism will receive a slightly different dose. Microorganisms passing close to a UV lamp will receive a greater UV intensity (and dose) than those at the limit of the reactor vessel. In order to compensate for this variability, a dose monitoring equation is developed including all key variable parameters and this dose is quoted as RED and represented in mJ/cm^2.

The process of determining a RED begins by developing a laboratory-derived curve of the log-reduction of a challenge microorganism versus a known UV dose to which the microorganism is exposed. This process is known as biodosimetry and uses a method known as collimated beam testing. As the relationship between UV dose and log-reduction is typically non-linear, a UV dose response curve is produced.

To determine a UV reactor's RED, the full-scale system is tested with the same challenge microorganism. The log inactivation of the challenge microorganism measured (log influent concentration minus log effluent concentration) during the full-scale testing is entered into the laboratory-derived UV dose response curve to calculate the RED of the reactor. The test conditions of flow rate, UV intensity, UVT and lamp status are also measured and recorded. From this exercise, a dose monitoring equation can be developed for RED as a function of controlled variables.

Importantly, RED values are specific to the challenge microorganism and the reactor process conditions. If a reactor is required to remove multiple pathogens, a RED may need to be determined for each pathogen, or it may simply be quoted for the most difficult pathogen to inactivate.

A challenge microorganism which shows very similar inactivation characteristics to pathogens (such as *Cryptosporidium* or E. coli) but is itself non-pathogenic, is generally selected. A challenge microorganism is selected because handling of the target pathogens during the validation testing can introduce health risks.

4.4. Reactor Validation Protocols and Guidelines

UV reactors need to be validated (or proven) against an approved or accredited protocol. This ensures a level of certainty that a reactor will provide a minimum level of disinfection/safety and achieve a customer's requirements and a manufacturer's claims.

Internationally, several organisations have developed industry accepted guidelines and validation protocols for the implementation of UV disinfection systems. These are summarised in Table 3 below.

Table 3 Internationally recognised UV disinfection standards, guidelines and protocols.

Place of Issue	Title	Notes
International	NSF / ANSI 55: Ultraviolet Microbiological Water Treatment Systems (NSF)	
Austria	Österreichisches Normungsinstitut (ÖNORM)	M 5873-1 March 2001
Germany	Deutscher Verein des Gas und Wasserfaches (DVGW)	W294 June 2006
United States	Ultraviolet Disinfection Guidance Manual (UVDGM) (US EPA)	November 2006
United States	Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse (NWRI/WRF)	NWRI-2012-04. August 2012

Seqwater considers validation against the protocols required by US EPA, as described in US EPA 40 CFR 141.720 (d)(2) and UVDGM, necessary for the implementation of UV reactors.

4.4.1. Comparing the Protocols

A US EPA (UVDGM) validated reactor may claim up to the corresponding log reduction value of a pathogen in accordance with Table 2 of this document.

By comparison, a DVGW validated reactor achieving a *Bacillus subtilis* RED of 40 mJ/cm^2 may claim no more than a 3.0 LRV for *Cryptosporidium* and *Giardia* (US EPA, 2006) when compared to the requirements of UVDGM. And no LRV for viruses may be credited to reactors validated against DVGW (WaterSecure, 2017).

ÖNORM, NWRI/WRF and NSF protocols are not discussed in this document and shall not be used in the validation of Seqwater UV reactors.

4.5. Feedwater Quality and UV Disinfection

The effectiveness of UV disinfection is subject to feedwater quality. If the water to be treated is not of a suitable quality, disinfection cannot be guaranteed and may not be effective.

UVT is a crucial measure of a water sample's suitability to UV treatment. Low UVT values result in poor exposure of target pathogens to the UV light, resulting in poor or no pathogen inactivation. Vendors provide minimum UVT requirements for their systems to achieve disinfection, with some quoting acceptable UVT values as low as 60-70%.

Increasing UV intensity can, to some extent, mitigate the negative influence of poor UVT, allowing disinfection to be achieved with lower UVT values. However, there is both a practical / effective limit to this, and a secondary operability / economic consideration as more power is required to provide higher intensities. Below a certain UVT, pathogen inactivation simply cannot be achieved or guaranteed as the amount of UV energy able to pass through the medium is insufficient. A few percentage points differences in UVT of a feedwater can significantly alter the power consumption and size of a reactor required to deliver a disinfecting dose. Applying feedwater pre-treatment to increase the UVT may be necessary to guarantee pathogen inactivation. At the very least pre-treatment may act to reduce capital and long-term operating costs.

The following are known to affect UVT adversely and directly as a result of absorption, shielding, or scattering of UV wavelengths:

- Algae
- Natural Organic Matter (NOM) i.e. Humic / Fulvic Acids and other colour causing components
- Chloramine
- Iron / Manganese
- Suspended Solids
- Oil & Grease
- Turbidity

Turbidity and suspended solids in water tend to result in UV absorbance and scattering, which in turn reduce the efficiency of UV disinfection. Particulates (e.g. suspended solids) can provide shielding to pathogens preventing UV wavelengths from contacting them. Generally, achieving a turbidity of less than 1 NTU, and ensuring suspended solids are less than (typically) 5 µm will assist in ensuring effective disinfection.

Other constituents such as dissolved solids may contribute to fouling or scaling of UV lamps which will result in reduced transmission of UV light for a given power input. Mechanisms exist to clean critical reactor parts, but reducing the formation potential through pre-treatment can be an effective means to improving operation.

4.5.1. Algae Growth

All UV lamps, particularly MP lamps, also emit light in the visible range which can promote algae growth. The growth rate depends on the available nutrients in the water, hydraulics (i.e. dead space), and the amount of visible light transmitted beyond the reactor.

The presence of algae in the water may reduce the UVT and interfere with the UV disinfection process.

4.5.2. By-products from UV Disinfection

By-products from UV disinfection can form either directly through photochemical reactions or indirectly through reactions with products of photochemical reactions. Photochemical reactions occur only with chemical species that absorbs UV light, and the resulting excited state reacts to form a new species. The concentration of by-product new species depends on the UV dose and the reactants concentration.

UV dose up to 200 mJ/cm^2 is known not to change pH, turbidity, dissolved organic content, bromide, nitrate, iron or manganese levels in water (refer to UVDGM). However, some literature has reported bromate formation at a lower UV dose from bromide and free chlorine under certain conditions.

The formation of common halogenated Disinfection By-Products (DBPs) Trihalomethanes (THMs) and Haloacetic Acids (HAAs) are found not to be significantly affected in the subsequent chlorination if the UV dose is maintained below 400 mJ/cm^2.

4.5.3. Chemical Pre-Treatment

The addition of chemicals as part of pre-treatment upstream of UV disinfection may affect the operation and efficacy of UV disinfection systems:

a. Chlorination should generally occur after UV disinfection. Where dosed upstream of UV disinfection:

i. Chlorine residual may, to a small extent, reduce UVT by absorbing UV light. Chlorine may also oxidise organic matters which in turn tends to improve UVT.

ii. Bromate, a possible human carcinogenic, may form in presence of bromide, chlorine, and UV light under certain conditions.

iii. . Seals and O-rings used in UV disinfection systems may also be susceptible to degradation where chlorine is dosed upstream.

b. The addition of potassium permanganate as an oxidant for iron and manganese removal may result in reduced UVT as permanganate is an absorber of UV radiation. Alternate oxidation processes or removal processes may need to be considered.

c. Ozone addition may improve UVT as a result of oxidising some of the organic content of water. However, if sufficient time is not given to dissipate the residual, the presence of dissolved ozone may reduce UVT as ozone will absorb UV radiation. Bromate may also form under certain scenarios in presence of bromide in source water.

d. Fluoridation of water can result in quartz sleeves in UV reactors becoming brittle. This can accelerate or lead to the onset of failures in quartz sleeves. This should not occur at typical levels achieved in bulk treated water, however, fluoridation should generally occur downstream of UV reactors.

e. The use of ferric chloride as a primary coagulant may result in reduced UVT due to the increased iron concentration which may absorb or scatter UV radiation. The presence of iron will also have a negative impact on the rate of lamp fouling as it may precipitate on lamp sleeves and sensors.

4.6. UV Disinfection System Components

UV disinfection systems used in water treatment comprise the following main components, which are discussed in further detail in Section 5:

- UV Lamps
- Transparent (typically quartz) sleeves that surround the lamps
- UV Lamp Ballasts
- Cleaning System
- The reactor / vessel housing to support the lamps and sleeves
- A power supply
- Monitoring instrumentation and the control system.

UV systems exist that operate as either open-channel flow systems or as closed vessel pressurised systems. Closed-vessel systems are used in drinking water applications due to the requirement for sanitary conditions.

4.6.1. UV Lamps

Mercury UV vapour arc lamps have been the mainstay of UV disinfection systems in water and wastewater treatment and are the only industry accepted solution for municipal water treatment applications.

Mercury UV lamps used by full-scale drinking water facilities can be subdivided into three further categories:

- Low-Pressure (LP)
- Low-Pressure High-Output (LPHO)
- Medium-Pressure (MP)

Lamp type will be determined based on plant size and vendor offering, although MP lamps may not be a competitive option for plants with low flows (approximately < 5 ML/d).

A summary and comparison between the three primary categories of mercury vapour arc lamps is included in Appendix A - Comparison of Mercury Lamp Types.

Research and development and emerging technologies continue to investigate and improve upon existing and alternate technologies, however, these are yet to be verified or adopted in the water treatment industry. For reference purposes, these additional technologies include:

- Electrode-less mercury vapour lamps
- Metal halide lamps
- Xenon lamps (pulsed UV systems)
- Eximer lamps
- UV lasers
- Light emitting diodes (LEDs).

From the above emerging technologies, the UV-C LED system shows significant potential due to ease of operation and having low capital, operational, and maintenance costs. It also has a long working life and doesn't require a lamp warmup time. While UV-C LED systems for treating drinking water for point-of-use are already commercially available, large-scale UV-C LED systems are still in the development and testing phase.

4.6.2. UV Lamp Sleeves

Lamp sleeves are a transparent cylindrical tube, typically made of quartz glass, which serve to insulate and protect the UV lamps housed within. The sleeve walls vary between manufacturers and application but are typically 2-3mm thick.

It is important they provide a high transmittance of UV light and are resistant to scratching and damage from particles or cleaning mechanisms used to remove fouling from them.

Lamp sleeves are capable of withstanding continuous positive pressures exceeding 8 bar(g) in operation. However, they are susceptible to negative pressures of just 0.1 bar, which may arise as a result of line breaks, rapidly closing valves, or accidental draining of reactors.

The design of UV reactor arrangements should therefore consider the need for vacuum valves to prevent negative gauge pressure conditions.

4.6.3. Fouling/Aging Factor

Fouling or scaling of the quartz sleeves protecting UV lamps can decrease the transmittance of the UV light through the sleeve into the water. Water quality, precipitation of mineral salts, oxidation reduction potential (ORP), temperature, pH and process conditions are the contribution factors to the rate and composition of the fouling materials. Other wetted components like sensor monitoring windows can also observe fouling which may have impact on the measured UV intensity and dose monitoring.

UV light emitted from aged lamps and sleeves will decrease compared to new sleeves and lamps. This can be estimated by the lamp and sleeve characteristics obtained by the UV manufacturer.

Lamp aging, lamp sleeve fouling and aging, and UV sensor window fouling all are accounted in the long-term performance of a UV reactor by the fouling/aging factor. This factor is calculated by multiplying the fouling factor by the aging factor and typically ranges from 0.4 to 0.9. This factor is used during the UV reactor validation testing to ensure that the reactor can deliver the required dose under aged and/or fouled conditions.

4.6.4. Cleaning Systems

UV systems shall have the capability of lamp sleeves cleaning while the plant remains in operation.

Mainly, the following different approaches for cleaning lamp sleeves have been developed, depending on the application:

- Off-line Chemical Cleaning (OCC)
- On-line Mechanical Cleaning (OMC)
- On-line Mechanical-Chemical Cleaning (OMCC)

For OCC systems, the chemicals used to clean lamp sleeves include citric acid, phosphoric acid or any other solution recommended by the UV vendor. These chemicals need to be consistent with NSF/ANSI 60 Standard: Drinking Water Treatment Chemicals – Health Effects.

OMC and OMCC systems use mechanical wipers that move along the lamp sleeve driven by electric motors or pneumatic piston drivers. In OMCC systems, a collar filled with the cleaning solution moves along the lamp sleeve to dissolve the fouling materials.

In addition, manual mechanical wipers cleaning systems are also available that require manual movement of the wiper by the operator to clean the lamp sleeve.

The necessary frequency of sleeve cleaning is determined based on the rate of fouling for a UV system.

4.6.5. UV Lamp Ballasts

Mercury vapour / amalgam arc lamps in UV disinfection systems cannot operate directly from AC power supplies and require a linear voltage-ampere (V-I) characteristic. They are negative resistance light sources, meaning once the arc is initiated, resistance decreases as current increases. Ballasts are therefore used to limit the line current when a voltage is applied to prevent lamp damage, and to provide lamp frequency control.

Two primary types of ballast are used in municipal UV disinfection systems:

- Electromagnetic Ballast
- Electronic Ballast

Electromagnetic Ballasts may be sub-categorised as transformer-based and inductor-based.

Ballast selection will be determined largely by vendor offerings and pairing with specific UV systems. A comparison of different systems should account for risks, reliability, criticality, asset life, maintainability, operability and whole life cost in conjunction with vendor proposals.

A summary comparison of the ballast types is included in Appendix B - Comparison of Ballast Types.

4.7. UV Reactor Arrangement Options

UV reactors may be installed in the following arrangements:

- Parallel
- Series
- Hybrid of parallel and series

Parallel:

Where two or more reactors installed in parallel streams, if one reactor is taken offline, the remainder are still able to operate and provide treatment to either full or part of the design flow. This arrangement allows for a reactor to be completely removed from the process for maintenance or replacement without affecting operation.

Series:

Where two or more reactors are installed in series, if one reactor is taken offline, the other reactor in the series is still able to provide disinfection at either full, or at least part of the design flow. Significant drawback of the series arrangement is that this does not allow a single reactor to be removed from service for maintenance or replacement without adversely affecting operation. The plant may need to be temporarily shut down and a replacement reactor or pipe spool need to be installed in its place.

Parallel + Series:

This is a hybrid arrangement where two or more parallel streams are installed with two or more reactors in series in each stream. This arrangement may reduce the total number of streams that would otherwise be necessary using parallel-only arrangements, while retaining full redundancy and throughput capability.

4.8. UV System Dosing Concepts

Two control strategies are available to ensure reactors provide the correct UV intensity to achieve the desired dose. The two strategies considered suitable are:

a. UV Intensity Set Point Approach

b. Calculated Dose Approach.

4.8.1. UV Intensity Set Point

The UV Intensity Setpoint approach uses only UV Intensity sensors to control and confirm operation of a reactor. A UV intensity sensor is mounted some distance from the UV lamps. By mounting the sensor a distance from the UV lamps, the intensity measured will fluctuate as a function of UVT. While in operation, as long as the UV intensity sensor reads above the setpoint intensity, the reactor's operation is valid. The UV intensity setpoints to achieve a log-reduction at a given flow rate are determined during the reactor validation.

One of the following operating strategies can be used for the UV Intensity Setpoint approach:

- Single-setpoint: A single setpoint is used for all flow rates that were validated. This may be energy inefficient at a plant where the throughput fluctuates or has a high turndown requirement.
- Variable-setpoint: Multiple setpoints are used for a range of flow rates. The required set point can be determined using a lookup table or equation. This system provides some improvement of energy efficiency by allowing a reduced output as flow decreases. This system has more complex operation compared to single-setpoint approach and more validation data are needed.

UV Intensity Set Point systems and reactors require the following instrumentation as a minimum:

- Dedicated electromagnetic flowmeter upstream or downstream of each reactor for variable setpoints.
- UV Intensity sensors mounted inside the reactor with sufficient instruments to comply with the selected validation guideline (i.e. UVDGM, or DVGW).
- Temperature sensors may be required by the vendor and mounted inside the reactor in accordance with selected validation guideline.

Although UVT monitoring is not required for the UV Intensity Set Point approach, the requirements of online UVT monitoring need to be assessed on a case-by-case basis to ensure that the UV reactor is only operated down to a minimum certain UVT value.

4.8.2. Calculated Dose Approach

The key feature of the Calculated Dose Approach is that the UV intensity output by the lamps is continuously variable according to an algorithm in order to maintain a desired dose. The lamp output to achieve the required dose is based on monitored parameters, typically:

- Flow rate
- UVI
- UVT

The dose algorithm must be developed with the measured parameters during reactor validation to ensure compliance of the system.

Calculated dose approach systems and reactors will provide the following instrumentation as a minimum:

- Dedicated electromagnetic flowmeter upstream or downstream of each reactor / reactor train
- UV Intensity sensors mounted inside the reactor with sufficient numbers to comply with the appropriate validation guideline.
- UV Transmittance monitoring in accordance with the appropriate validation guideline.
- Temperature sensors mounted inside the reactor in accordance with selected validation guideline.

The lamp UV output intensity is variable over the output range of the ballast and is automatically adjusted (incrementally) by the system to achieve the calculated required dose. The output will continuously adjust based on variations in any of the key parameters mentioned above.

This system offers the benefit of improved energy efficiency in plants with high turndown or variable flow, and when better than expected UVT values occur. It may also allow a system to compensate for a failed lamp, allowing the remaining UV lamps to increase intensity to accommodate a dark lamp. It does, however, result in a more complex control system requiring additional instrumentation, monitoring, programming and potentially integration of external (to the UV system) signals.

Only systems validated using the UVDGM protocols are acceptable under this mode of operation.

4.8.3. Dose Approach Comparison

Table 4 Comparison between two dosing approaches

	UVI Setpoint Approach	Calculated Dose Approach
Advantages	Reduced monitoring requirements and instrumentation (fewer variables). Simplest validation tests.	Improved energy efficiency – particularly in high throughput facilities. Intuitive operation / data gathering (the calculated dose can be compared to the required dose for log inactivation).
Disadvantages	Poor energy efficiency if plant operates below design flow. Risk of producing unwanted by-products from photolysis if plant operates at much lower flow rates than the design flow.	Additional UVT monitoring. Data analysis to develop dose-monitoring equation.

4.9. Mercury Contamination

UV lamps used in UV disinfection systems contain Mercury. Individual MP lamps contain higher quantities than LP and LPHO lamps, typically up to about 400mg of Hg, although this may increase for large systems and lamps.

Lamp and sleeve breakages are rare occurrences but may happen. The breakage may occur during operation due to internal stress and external mechanical forces such as wiper jams, water hammer, resonant vibration, and impact by objects, negative pressure from line breaks or accidental rapid dewatering of the reactor. In addition, breakages may also take place during handling, replacement, and maintenance activities.

In most systems, the mass of mercury held in reactor lamps will be such that, even if multiple lamps break and leak mercury when the UV reactor is installed upstream of a reservoir, the concentration of mercury released will be significantly and sufficiently diluted to eliminate any health hazard to populations.

Nevertheless, a risk assessment and management plan shall be completed for all installations to identify the likelihood, risk, outcome and response of a lamp breakage.

5. UV System Design Specification

The following sections define the minimum requirements for design, selection and installation of UV reactors and instrumentation.

When designing a new facility or retrofitting an existing and incorporating UV disinfection, consideration shall be given to the plant's size, availability requirements, criticality, log reduction requirements and level of resourcing dedicated to operation (e.g. 24 hour servicing, vs 24 hour monitoring, vs remote sites etc.). These factors may influence control strategies, redundancy requirements, and equipment selection. To assist in decision making to select a UV system, this document provides a guidance framework at the end of this chapter.

5.1. Plant Disinfection Strategy

a. All plants shall provide a minimum of 2 barriers for removal of pathogens.

b. Any water source with an identified protozoa risk shall include at least one physical separation barrier to pathogens, which shall be installed upstream of UV reactors.

c. Any new or retrofit plant using UV disinfection for pathogen inactivation shall include chemical disinfectant dosing for residual maintenance. Seqwater will not accept a disinfection system using UV if it is not proposed in conjunction with a chlorination / chloramination system for residual maintenance.

5.2. Goal of UV Disinfection Systems

a. UV disinfection may be selected for primary disinfection or used as an adjunct to an existing chemical disinfection system, requiring an additional pathogen barrier.

b. UV disinfection may be suitable to achieve the following pathogen log reduction values:

   i. Protozoa LRV ≤ 4.0

   ii. Bacteria LRV ≤ 4.0

   iii. Virus LRV ≤ 2.0

   iv. Virus LRV > 2.0; alternate treatment processes should be considered first.[3]

c. The LRV for pathogens required to be achieved through UV disinfection should be determined on a per project basis and based on catchment risk assessments and existing or proposed treatment processes. Table 2 provides guidance on the UV dose necessary to achieve inactivation of pathogens.

d. Designers should consider the need to size downstream chemical disinfection processes to accommodate primary disinfection needs in the event of UV disinfection system failure.

5.3. Key Design Parameters

The key design parameters which affect the sizing of the UV reactors and associated support facilities are listed below:

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[3] Chemical disinfection is generally far more effective in virus treatment than UV disinfection. Achieving high LRVs for viruses is likely to result in unnecessary capital and operational costs for UV systems.

- Target pathogen inactivation,
- Water quality,
- Flow rates,
- Reactor validation requirement,
- Fouling and aging factor (i.e. for sleeve, lamp, sensor window),
- Power quality.

5.4. Pre-Filtration and Screening

a. Any plants not intending to use upstream filtration processes (e.g. membrane or media filtration) and using UV disinfection shall include an upstream, in-line filters (e.g. cartridge filters or similar) to comply with clause 5.2.a.:

   i. Where there is an identified risk of *Cryptosporidium*, such filters shall provide filtration to ≤1µm and shall be US EPA validated; or

   ii. Where there is no identified risk of *Cryptosporidium*, such filters should provide filtration to ≤5µm subject to design assessments.

b. Plants using upstream particulate media filters (e.g. sand, gravel, GAC etc. media) shall include a pre-reactor screen sized to ≤0.5 mm such as a Y-strainer or a vee-wire flat screen4.

c. Where the installation of a Y-strainer or a flat screen may add additional significant head loss to a gravity system, an alternative design with a low velocity area to trap sand and other objects shall be included at the inlet channel of UV reactors. This arrangement shall be provided while meeting pipework requirements as discussed in Section 5.13.1.

5.5. Feedwater Quality Parameters

Generally, feedwater quality should be in line with the guidance provided in “Table 10.6 Guideline values for physical and chemical characteristics” of the Australian Drinking Water Guidelines (ADWG) 2011.

Table 5 below provides guidance on the specific feedwater quality parameters that should be achieved to enable effective UV disinfection.

Table 5 Minimum feedwater quality parameters (achieved by upstream treatment) for the application of UV disinfection.

Parameter	Unit	Value	Detail
Colour	HU	<15	Guideline value provided in ADWG – maximum allowable for final water quality.
		<5	Recommended to optimise UV operation – note this is lower than ADWG limit.

[4]Seqwater has experienced damage to lamp sleeves as a result of objects from upstream filters carried through the process.

Parameter	Unit	Value	Detail
Calcium Carbonate Precipitation Potential (CCPP)	mg/L $CaCO_3$	-5 to 0	This is a general guide – achieving a CCPP in this range will help prevent scale formation in UV reactors.
Hardness	mg/L $CaCO_3$	≤120	High hardness can lead to scaling of quartz sleeves and sensors. This is particularly relevant in MP reactors where high lamp temperatures may lead to rapid scale formation. While this is not a mandatory limit, concentrations above this may require pre-treatment and water softeners. Consider also CCPP.
Iron	mg/L	<0.3	Guideline value provided in ADWG
		≤0.05	Recommended to minimise fouling of UV systems
Manganese	mg/L	<0.05	Is the 'desirable' level in ADWG (0.1 mg/L is the 'aesthetic' guideline level).
		≤0.02	Recommended to minimise fouling of UV systems.
Turbidity	NTU	<1	This is a mandatory requirement that must be achieved to implement UV disinfection
UV Transmittance	%	>85[5]	Raw water source selection or pre-treatment should aim to achieve this or better to minimise capital and operational costs.

5.6. UV System Installation

5.6.1. Location and Orientation

UV Systems:

a. Shall be installed downstream of any coagulation, flocculation, clarification and filtration stages.

b. Should be installed upstream of chemical disinfection, fluoridation and treated water pH correction processes.

c. If chlorine or ozone-based chemical is required for upstream chemical disinfection or other purposes, bromate formation potential in UV disinfection application must be investigated in detail where bromide presents in source water, refer to Section 4.5.3 for further information.

d. Should be installed upstream of reservoirs and treated water tanks. If an installation downstream of a reservoir or treated water tank cannot be avoided, protection to the network or end user must be provided, and include:

[5] In some circumstances, including water sources with high organics loading, this target may not be feasible. Designers should consider the feasibility of reducing organics through pre-treatment and discuss with UV system vendors.

i. Provision of a screen on the reactor outlet to capture glass in the event of a sleeve failure.

ii. Provision of a mercury trap or similar arrangement to minimise the risk of mercury contamination into the network.

iii. Appropriate risk assessments and response plans in the event of an incident which may result inadequately disinfected water entering the network.

e. May be installed indoors or outdoors. Where installed outdoor:

i. Shall be installed with a shelter that ensures the reactors, ballasts, and control panels and associated equipment are protected from direct sunlight and rain under all circumstances and provide protection to maintenance personnel from the elements.

ii. All equipment and construction materials shall be suitable for the installation environment with appropriate Ingress Protection (IP) rating as per standard specification of *E-SPE-STD-001 Electrical Design and Construction*

iii. Reactors, control panels and associated equipment shall be installed on a concrete slab.

f. Reactor arrangements shall allow even flow distribution and be capable of limiting the flow deviation between reactors to no more than ±5%. Hydraulic modelling shall ensure any error in flow deviation does not cause a reactor to exceed its design / validated flow rate, see additional details for flow measurement in Section 5.11.

g. Shall be designed and installed such that lamp sleeves are always fully submerged in water under all operating conditions, including during start-up and during shutdown. This may be achieved by appropriate selection of reactor design, installing reactors at low points, and using appropriate pipework layout, flow control structure and valving.

5.6.2. Access

The design and system selection shall account for:

a. Access to reactors and components for maintenance.

b. Lifting of reactor units for maintenance.

c. Space for removal of lamps, lamp sleeves, and reactor modules.

d. Any lifting aids for reactors and lifting cradles for lamps and sleeves to assist maintenance teams in safe practices.

5.7. UV Facility Hydraulics

A detailed assessment of system hydraulics of the UV facility is required after the selection of the reactor installation location, number of UV reactor trains and reactor arrangements. The hydraulic evaluation shall include:

a. Inlet and Outlet Pipe Configuration: to ensure that UV dose delivery is equal or greater than the UV dose delivered for the UV reactor validation. Refer to Section 5.13 for other relevant requirements.

b. Flow distribution and control: to ensure that the flow through each reactor is equal and matches with the operating conditions of the reactor validation.

c. Reactor water level: to ensure that UV lamps are always submerged under water to prevent overheating.

d. Air relief valve: to keep free of air to prevent lamp overheating.

e. Pressure relief or vacuum relief valves or hydropneumatics tanks: to operate the reactor within the recommended pressure range (i.e. negative pressure or surge effects) of the lamp sleeves and lamps.

f. Any potential impact on hydraulic gradients upstream and downstream of UV reactors that may arise due to the installation of new reactors in an existing WTP shall be assessed in detail.

5.8. Process Conditions

a. The UV system shall be selected considering the maximum, minimum and average flow rates. The maximum flow rate must be within the reactor validated range as documented. The minimum flow rate is important to avoid overheating more importantly with MP lamp reactors.

b. The expected maximum and minimum system design pressures shall be considered for the selection of a UV reactor particularly for the lamp sleeves and reactor housing.

c. Maximum feedwater temperature shall be considered for the reactor selection to ensure that the reactor temperature does not exceed the recommended value during operations, start-up and shutdown.

5.9. UV Reactors and Components

5.9.1. Reactor Type

UV reactor vessels shall be of the closed-vessel system type. Open channel systems shall not be used.

5.9.2. Materials and Construction

a. UV reactors, flanges, screens and fittings shall be fabricated in 316L Stainless Steel as a minimum. All materials that may be exposed to UV radiation shall be resistant to UV radiation emitted by lamps.

b. Material selection shall account for any upstream chemical dosing and cleaning solutions used as part of online or offline cleaning.

c. Where a new UV system is installed, an assessment of the upstream chlorine dosing system (if any) is recommended to avoid any potential exposure of concentrated chlorine to the UV reactor materials that may bleed from the dosing system during shutdown. This is to ensure that a high level of chlorine concentration will not result in severe corrosion to stainless steel reactors and other components.

5.9.3. Lamps

a. All UV disinfection systems shall use mercury vapour / mercury amalgam UV lamps for the generation of UV radiation. This shall be reviewed as alternate technologies are improved and new ones developed.

b. In future, when validated large scale reactors with UV-C LED lamps are commercially available, UV-C LED lamps may be considered as they may provide significant benefits as mentioned in Section 4.6.1. However, they must be evaluated with appropriate design review including reactor validation data, operations and maintenance issues, and performance experience for drinking water treatment applications.

c. Lamps shall be removable, one at a time, without removing the lamp sleeve.

d. Lamps shall be replaceable on-site by Seqwater personnel who have received appropriate training.

e. Only one lamp shall be installed inside a single sleeve.

f. Systems should use lamps available from at least 2 currently active lamp manufacturer's without modification to the system.

g. The selection of appropriate lamp types (e.g. LPHO vs MP) should be supported by a technical and whole life cost assessment.

5.9.3.1. MP Lamps

MP mercury lamps should be installed in reactors parallel to the ground and preferably in a horizontal plane (or near to the centreline of the reactor) to minimise the risk of lamp overheating.

5.9.4. Ballasts

a. Where installed in kiosks or panels, ballasts shall be sufficiently cooled and ventilated to prevent overheating.

b. A temperature sensor should be included in ballasts to monitor temperature, readable through the SCADA and HMI.

c. Ballasts shall be of a modular design allowing for quick disconnect and replacement by Seqwater personnel using an available spare.

5.9.5. Lamp Sleeves

Lamp sleeves shall:

a. House a single lamp per sleeve.

b. Provide a minimum of 89% UV transmittance at 254 nm.

c. Be resistant to UV degradation over the life.

d. Be made of a single piece of Type 214 fused quartz circular tubing. Alternative materials may be considered subject to Seqwater approval and provided it can be demonstrated they are of equal or superior function and capability.

e. Be replaceable, in situ by appropriately trained Seqwater personnel during a reactor shutdown.

5.9.6. Sleeve Cleaning

Reactor lamp sleeve cleaning system is described in Section 4.6.3. In general, online systems either OMC or OMCC cleaning is recommended for large systems. OCC can be used for medium to small systems with the exception that all MP lamp systems shall include online cleaning systems for lamp sleeves irrespective of the plant size.

a. For Off-line Chemical Cleaning (OCC):

    i. UV systems shall have capability to remove one reactor train / stream from service for maintenance and manual cleaning while the plant remains in operation.

    ii. The design shall detail the proposed management and appropriate treatment or disposal of cleaning solutions.

    iii. The vendor shall be consulted on preferred cleaning methodologies. Typically, a DN25 connection, with isolation ball valves, upstream and downstream of the reactor should be allowed for cleaning purposes and passing of a cleaning solution – valving and isolation requirements should account for this. These cleaning valves may be incorporated with drain valves. Alternative cleaning methodologies may include facility to insert a sparging lance for cleaning.

b. For On-line Mechanical Cleaning (OMC) and On-line Chemical Mechanical Cleaning (OMCC):

    i. The wiping frequency, number of strokes, and timer interval of OMC systems shall be operator adjustable.

ii. Any proposed wiper system shall be designed such that it does not damage or scratch quartz sleeves which could reduce UVT over the design life.

iii. Wiping systems shall be powered from the reactor ballast.

A guideline is provided in Table 6, Section 5.22 to select the cleaning method for different reactors, but vendors shall advise the best method of cleaning and design requirements / considerations for their system.

Any chemical used for cleaning should be UV resistant. Any cleaning solution recommended by vendors shall be approved by the Seqwater Principal Water Quality prior to use.

5.10. Instrumentation

Refer to Section 3.12 for general requirements on instrumentation. Specific requirements for instruments associated with a UV system is provided below.

5.10.1. UV Intensity Sensors

a. UV Intensity sensors:

i. Shall be of the *Germicidal* type as defined in US EPA, UVDGM.

ii. May be:

1. Mounted internally to the reactor in contact with the water flow (wet sensor); or

2. Mounted externally using a monitoring window (dry sensor) to detect UV wavelengths.

iii. Shall include a cleaning mechanism like lamp sleeve cleaning.

b. The number of intensity sensors supplied in a reactor shall be based on the lamp category with the following considerations:

i. MP Systems shall include one Intensity Sensor per lamp.

ii. LP/LPHO systems shall include at least one UV Intensity Sensor per bank of lamps.

iii. The final installed location of the UV Intensity Sensors should be in accordance with their position during the reactor's validation where applicable.

5.10.2. UV Transmittance Sensors

a. UVT sensors:

i. Shall be installed in the pipework upstream of the UV reactors and downstream of any pre-treatment processes. Note that the requirements of online UVT monitoring for UV set point dosing approach shall be assessed case by case basis.

ii. Shall include online wiper or ultrasonic cleaning mechanism.

iii. Shall measure the transmittance at 254 nm.

b. The number of UVT sensors supplied in a reactor shall be:

i. A minimum of one UVT sensor to monitor the combined inlet UVT to all reactors.

ii. For calculated dose systems, it is strongly recommended to use two UVT sensors in a master/slave configuration for the combined reactors feed. The sensors should be used to alert operators with a deviation greater than a nominal 5%.

iii. The vendor shall be consulted for the arrangement of UVT sensors and the need of a single UVT sensor per train.

c. Where needed, each UVT sensor line shall be fitted with a sample pump with the return line back to the main process.

d. Each UVT sensor sample line shall be fitted a valve for isolation and with a flow switch to raise an alarm when no flow is detected to be in line with the requirements of standard specification I-SPE-STD-015 Instrumentation.

e. The sensor shall be located to minimise the likelihood of exposure to air bubbles which can cause erroneous readings.

5.10.3. Temperature Sensors

a. Temperature sensors should be included in reactor installations based on vendor recommendations.

b. Temperature sensors shall be capable of measuring the maximum water temperature that could be achieved in a reactor, which will be dependent upon lamp type.

c. A hard-wired temperature switch may be acceptable for lamp protection and should be assessed on a per-project and vendor specific basis.

5.10.4. Low Liquid Level Switches

Liquid level switches should be included to shut down the UV reactor at low liquid level based on vendor recommendations. This is to avoid potential overheating scenarios at a low liquid level within the UV reactor.

5.10.5. Turbidity Sensor

a. Turbidity monitoring will not typically be part of the UV system package, but rather an upstream process such as filtration. Existing turbidity monitoring shall be used for verifying feedwater quality into UV systems.

b. If upstream turbidity monitoring does not already exist, a UV system turbidity analyser is required.

c. Where a turbidity sensor is required specifically for use upstream of a UV system and is not provided as part of an upstream process, the sensor shall meet the requirements of I-SPE-STD-016 Turbidity Analysers.

5.11. Flow Measurement

a. All Dose Control Approach UV systems shall include a dedicated flowmeter per reactor stream.

b. For UVI Set point Approach with a single set point system, a single flowmeter shall not serve for more than two reactors. For variable set points, this is recommended to include a flowmeter per reactor.

c. The flow rate through a UV reactor must be within the validated reactor flow range.

d. Flow meters shall be electromagnetic type and shall comply with the requirements of M-SPE-STD-009 Flow Meters.

e. Flow switches can only be used as a secondary means of flow identification.

f. Where UV reactors are installed at individual filter outlets, the flow rate from the filters can be used for the flow rate through UV reactors.

g. Appendix D shows a number of typical flow and instrument arrangements for UV systems.

5.12. UV Reactor Number, Size and Layout

a. Reactors shall be sized to:

   i. Ensure the plant is capable of consistently treating the maximum daily design flowrate with the following requirements in between 20 to 23 hours of production depending on the plant size:

      1. A minimum of 1 reactor offline/in standby.

      2. 95th percentile water quality conditions, including UVT.

      3. Lamp aging and fouling factors are accommodated.

   ii. Ensure frequent cycling (on/off) of reactor lamps is avoided as this will reduce lamp life. This will need to be balanced with the number of reactors installed.

b. UV systems shall fulfil the following redundancy requirements:

   i. A minimum of 1 duty and 1 standby reactor shall be supplied for any system.

   ii. The number of reactors supplied should provide a minimum of 25% standby reactors, rounded up to the next whole reactor.[6]

   iii. When lamp banks are installed in series, the ability of lamp power modulation or change the number of lamps energized should be considered to determine the UV reactor redundancy and achieve energy efficient operation.

c. Reactors arrangements and isolation:

   i. UV reactors shall be installed in parallel streams to meet the redundancy and flow requirements of the system.

   ii. Reactors may only be installed in series, whether to provide further redundancy or capacity provided:

      1. This does not inhibit the ability to carry out maintenance activities while the plant is in operating.

      2. Redundancy requirements as stated above are still maintained.

      3. There is a minimum of two parallel streams installed.

   iii. Each UV reactor shall be fitted with isolation valves allowing maintenance activities to be undertaken.

d. Standby reactors shall be operated such that:

   i. A minimum of 1 standby stream shall be maintained in operation to allow rapid adjustment to process changes.

   ii. It is only acceptable for facilities to maintain their standby reactor(s) in duty / duty operation for rapid flow adjustment or other reasons only for a short period of time if this has been subjected to a risk assessment as process adjustment to faults will be generally slower.

[6] Example: A UV system requiring 5 reactors would require minimum 2 standby reactors.

5.13. Pipework, Valves and Fittings

5.13.1. Pipework

a. The length of straight pipe upstream of each reactor shall be the length of straight pipe used in the validation testing plus a minimum of five (5) pipe diameters.

b. The UV reactor upstream inlet piping shall not have any changes in pipe sizes for the length of at least ten (10) pipe diameters.

c. The UV reactor inlet and outlet conditions shall match those used during validation for at least ten (10) pipe diameters upstream and five (5) diameters downstream.

d. Piping design shall ensure that the UV reactors always submerge fully under water as per Section 5.6.1.

5.13.2. Isolation and Flow Control Valves

a. As a minimum, one automated isolation valve with open/close position switches shall be provided and installed downstream of each reactor (not in a combined stream). An additional automated upstream isolation valve with position switches should be considered per reactor stream if required by the design.

b. An upstream manual isolation valve shall be provided as a minimum for each reactor if an automated isolation valve is not installed.

c. The position and type of valves shall be coordinated with reactor suppliers to ensure they do not affect reactor validation.

d. Automated isolation valves shall be designed with a fail-safe closed position.

e. Designers should consider that any water volume between a reactor and downstream isolation valves will not be treated on reactor start up – this volume shall be minimised as much as possible without affecting reactor validation.

f. Where hydraulic arrangement alone cannot achieve an even flow split between reactor trains across the design flow range (from minimum to maximum flow), control valves shall be used:

   i. A control valve shall be provided for each reactor stream and should be installed in downstream. Generally, the same valve should not be considered for isolation and control.

   ii. The operation of a control valve should not develop a different velocity profile within the reactor as used in the validation test.

g. Automated isolation and control valves to reactors should be slow opening and slow to moderate closing to prevent surging in vessels which could result in damage to quartz sleeves and lamps.

h. Valve seats and other in-pipe seals used adjacent to the UV reactors shall be resistant to UV lights.

i. Where automated isolation and/or control valves are provided, a suitable surge analysis for pressure, flow and level should be performed and assess the impact to the plant and the UV reactor components when isolation and control valves are suddenly closed due to the trip/shutdown of the UV reactor.

5.13.3. Drains

a. Reactors and the surrounding pipework shall be fully drainable.

b. A tapping and ball valve should be incorporated into reactors to allow them to be drained. This tapping and fitting will typically be DN 25. All tapping and modifications to reactors shall be completed by the Vendor.

c. If a tapping and drain is not available on the reactor, or cannot be fitted, the surrounding pipework shall allow for complete draining of the reactor between the upstream and downstream isolation valve.

d. Reactor drains should be directed to a floor drain or similar location for management flows but shall have the ability to be manually intercepted in the event of contamination or internal lamp and sleeve breakages.

5.14. Air/Vacuum Valves and Safety Devices

a. UV reactors and the surrounding pipework shall be protected from air entrainment. The design should include air release valves or be designed to prevent accumulation of air in reactors. These requirements should be discussed with the vendor.

b. UV systems shall include vacuum protection (e.g. vacuum valve) as lamp sleeves are highly susceptible to damage as a result of vacuum. These requirements should be discussed with vendors.

c. The designer shall ensure the risk of negative pressures occurring in the reactor as a result of leaks, rapid draining, or surging shall be eliminated as far as practicable through design to protect lamp sleeves and lamps.

5.15. Cooling Water

Consideration shall be given to the effect of water temperature in reactors during start-up and shut down, or isolation periods. If cooling water is provided, the design must allow for wasting of this water with appropriate connections, or accounting for the volume and its risk to the total treated water volume.

Where recommended by the UV manufacturer, the option of recirculation pumps around the UV reactors to recirculate water at a low flow rate from reactor downstream to upstream should be considered. This is to keep the reactors cool when the UV reactors are required to maintain in energised stand-by mode particularly where the plant needs to shutdown frequently. The recirculation pumps, where recommended, are to avoid frequent start-up of the UV reactors, eliminate the plant start-up waiting time for the reactors warm-up and ensure guaranteed lamp life by reducing the number of on/off cycles. Pipework must be designed accordingly to achieve the outcome.

Where recirculating pumps are included, flow switches shall be installed in the discharge pipework to raise alarms for zero or very low flowrates when pumps are turned on.

5.16. UV System Bypass

UV disinfection systems shall not include an installed / valved bypass around the UV reactors. If a risk assessment deems safe to do so, a reactor may be removed and replaced with a pipe spool temporarily.

5.17. Power Supplies

a. UV system ballasts are extremely sensitive to power quality fluctuations. Seqwater has experienced plant shutdown and restart events as a result of out of tolerance power supply, leading to plant downtime. Equipment selection and design must consider manufacturer specified tolerances on power quality, including voltage sag/swell and power interruptions.

b. A plant risk assessment should consider the risk of downtime and the cost to include power quality management solutions such as uninterruptible power supplies (UPS), automatic voltage regulating devices, and harmonic filters.

c. The power supply voltage and total load requirements shall be confirmed with the manufacturer.

d. The power supply system shall have adequate power modulation capacity to prevent overdosing and subsequent chlorine reduction, where applicable.

5.18. UV Dose Strategy

a. The dose monitoring strategy establishes the operating parameters to achieve the desired UV dose. The dose monitoring strategy defines how the reactor is operated, controlled and validated. Section 4.8 describes the two dose approaches (i.e. UVI Setpoint Approach and Calculated Dose Approach) that UV manufactures commonly design their reactors to operate.

b. UVI set point approach is generally recommended for small to medium systems and where virus LRV is not required. This approach can be used with a single or variable UV Intensity setpoint operation.

c. Calculated Dose Approach is normally recommended for a relatively large system or where the requirement of virus LRV is ≥ 2.0. For this approach, the validated dose (the calculated RED dose divided by the validation factor) needs to be equal or greater than the required dose (i.e. a single setpoint).

d. Further guidelines to select the dose approach is provided in Table 6, Section 5.22.

5.19. Reactor Validation

a. UV reactors shall be provided with US EPA validation against the protocols of US EPA 40 CFR 141.720 (d) (2).

b. UV reactor testing shall be by an independent third-party certification company.

c. Validation testing shall include full-scale testing of reactors according to the selected protocols.

d. US EPA validated systems provide up to a 4.0 LRV in any of Protozoa, bacteria, or viruses.

e. In rare circumstances, and subject to Seqwater approval, a DVGW validated reactor may be acceptable. Such a reactor may claim the following LRVs:

    i. Zero (0.0) LRV for viruses

    ii. ≤ 3.0 LRV for *Cryptosporidium* and *Giardia* and bacteria.

f. Pre-validated UV disinfection reactors may be accepted by Seqwater provided that the validation testing conditions, design configuration, UV-dose response curve, operating conditions and dose-monitoring strategy are representative of site conditions.

g. Reactors shall be revalidated if changes occur that substantially change their performance, such as feed water quality, fouling/aging factor, increased flow rates, installation arrangement, upstream chemical dosing or treatment processes. Where in doubt, vendors should be engaged to verify if further validation may be required.

h. Reactors shall be supplied with a validation report to allow detailed assessment and determination of operating parameters. The validation report shall include:

    i. For UVI setpoint approach: UVI setpoint(s) and the minimum RED value.

    ii. For calculated dose approach: All RED values with associated test conditions used to create a dose monitoring equation.

i. Validation test results should be adjusted if the site-specific fouling/aging factor is lower than considered during the validation testing.

5.19.1. Site-Based Validation

a. In certain circumstances, it may not be possible to install a reactor in the validated arrangement, or site conditions may be sufficiently different from the validated arrangement such as to invalidate facility completed testing. In this case, the following methods of reactor validation may be accepted subject to approval by the Seqwater Principal Engineering Standards and Assurance:

   i. CFD modelling

   ii. Site-based validation.

b. Site-based validation may require additional considerations to allow implementation, including space requirements and modifications to reactor installations and connecting pipework:

   i. Feed and sample ports:

      1. Injection of challenge microbes,

      2. Injection of absorption material.

   ii. Static mixers,

   iii. Space for tanks,

   iv. Laboratory testing facilities,

   v. Disposal of treated water.

5.20. Other Design Considerations

5.20.1. Chlorination

a. Chlorination should, in most circumstances, occur after UV disinfection. In some circumstances pre-chlorination process may be included or recommended for iron / manganese removal, control of biological fouling, re-treatment from a reservoir or disinfection. Where this is the case, the design shall:

   i. Ensure appropriate materials are selected for reactors to prevent damage to components and seals etc. The vendor shall be consulted to agree a maximum free chlorine concentration.

   ii. Assume a free chlorine reduction across a reactor as follows, unless an alternate reduction can be demonstrated in operation or through testing, or if the vendor is able to provide alternate data:

      1. 0.2 mg/L reduction in free chlorine in reactors delivering a dose of up to 50 mJ/cm^2.

      2. 0.3 mg/L reduction in free chlorine in reactors delivering a dose of 50 - 100 mJ/cm^2.

      3. Reactors delivering a dose greater than those detailed above should be assessed on a case-by-case basis to determine an appropriate free chlorine reduction.

   iii. Include a filtration stage downstream of the pre-chlorination (upstream of UV reactors) if the iron and manganese concentrations in the reactor feedwater will exceed 50 µg/L and 20 µg/L respectively.[7]

[7] This is due to the increased likelihood of fouling on lamp sleeves as a result of metals oxidation.

iv. Ensure minimum risk to the formation of bromate or other harmful by-products from interactions of chlorine, bromide, UV light and others under all operating conditions as described in Section 5.6.1.

5.20.2. Mercury and Lamp Breakage Management

a. Networks that have no reservoir (settling volume) between UV reactors and transmission pipework are at greater risk of contamination in the event of lamp and sleeve failure. These systems should be avoided, and reservoirs placed between UV reactors and networks. Where this cannot be achieved, a risk assessment and management plan should address the risks. Item d. below provides some guidance on minimising the risk of contamination.

b. Each project shall develop a site-specific lamp breakage response plan in consultation with the UV reactor vendor. The response plan shall also include the management of disposal of spent UV mercury lamps.

c. A hard stand area should be provided under and around the reactors to ease cleaning of any mercury contamination in the inadvertent dropping of a lamp during insertion or removal.

d. The following process elements should be considered to reduce the risk of mercury making its way into treated water tanks and networks:

   i. Install reactors upstream of reservoirs to provide settlement of mercury and facilitate clean up should a lamp and sleeve fail.

   ii. Consider using solid amalgam lamps in which the mercury is in a solid form when offline and cool, which may be more readily captured should a lamp and sleeve fail.

   iii. Consider installing a relatively fast acting, spring-return actuated valve on the inlet and outlet of each reactor (slow open, moderate fast close) capable of closing relatively quickly, which can isolate a reactor in the event of a lamp breakage (failure).

      1. The downstream valve may be placed far enough downstream of the reactor to accommodate the closing time of the valve. However, this should be balanced against Item 5.13.2.e of this standard.

      2. A suitable surge analysis should be completed to ensure additional risk is not introduced into the system (e.g. further risk of damage to reactors and lamps, appurtenances, and other systems of the plant) and must be balanced against the requirement of Item 5.13.2.g.

   iv. In large plants, consider installing MP lamps to reduce the total number of lamps (vs. LP or LPHO lamps) thereby reducing the overall risk and consequence. While MP lamps may contain a little more mercury, large systems will require significantly fewer lamps overall, reducing exposure and likelihood of a breakage.

   v. Consider installing a mercury 'trap', consisting of a Tee-piece of pipe with a radial bend intended to capture any broken glass and mercury. These should not typically be required or installed unless absolutely necessary. The discharge velocity must be controlled such that settling of glass and mercury may be achieved. The effectiveness of these in practice is poorly documented in literature. An example is shown in Figure 2 below.

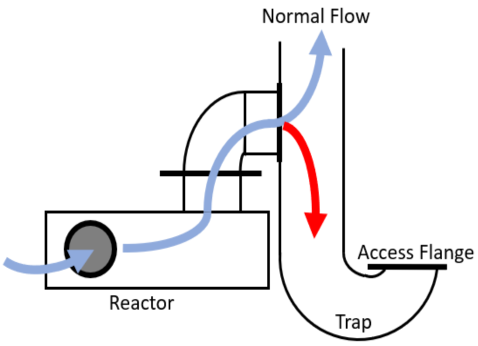

Figure 2 Example of a mercury trap.

e. Alternatively, where feasible, a low velocity area should be considered at the outlet of UV reactors for the collection of lamp breakage materials and settled mercury.

5.21. UV Disinfection System Datasheet

Appendix C includes the Template B-TMP-STD-013 for UV Disinfection System Datasheet. The datasheet shall be prepared and/or updated at each project phase to record and communicate technical specifications about the selected UV disinfection system.

The datasheet shall include information on feed water characteristics, process conditions, reactor design specifications, performance requirements, power supply, process control, and associated instruments.

5.22. Facility Categories and UV System Requirement Guidelines

The guidelines framework provided in Table 6 is intended to assist in decision making for control strategies, system and redundancy requirements, and equipment selection for a UV disinfection system.

This guideline divides facilities into 6 categories. Categories are determined on the basis of plant throughput, plant availability requirement, protozoa and virus log reduction value required.

This should be considered as a guide only; projects should always be assessed on an individual basis to determine the final needs.

Table 6 Guidelines for determining facility category and selecting facility requirements.

Criteria	Category 1	Category 2	Category 3	Category 4	Category 5	Category 6
Category Determining Factors						
Design Flow	≤ 10 ML/d	≤ 10 ML/d	10 – 100 ML/d	10 – 100 ML/d	≥ 100 ML/d	≥ 100 ML/d
Plant Availability	N/A	≥95%	≥50%	≥95%	≥50%	≥95%
Protozoa LRV	≤ 4					
Virus LRV	N/A	≥ 2.0	0.0 – 1.0	≥ 2.0	N/A	≥ 2.0
Category Specific Requirements						
Preferred Dosing Approach	UVI Setpoint (single)	UVI Setpoint (single)	UVI Setpoint (variable)	Calculated Dose	Calculated Dose	Calculated Dose
Total Min No. of Reactors (Note 1)	2	2	2	3	4	4
Min. standby Reactors (Note 2)	1	1	1	1	1	2 (Note 3)
Reactor Arrangement	Parallel					
Cleaning System	OCC	OCC	OMC	OMC/ OMCC	OMC/ OMCC	OMC/ OMCC
Max number of reactors per flowmeter	2 (Note 4)	2 (Note 4)	1	1	1	1
Min UVT sensor (Note 5)	Master	Master	Master	Master and redundant	Master and redundant	One per reactor plus master

Note 1: Number of reactors are arbitrary selected with minimum two (2) reactors.
Note 2: Redundancy is determined with minimum 25% of reactor standby requirements except for Category 6 reactors.
Note 3: One additional standby reactor included considering design flow, availability and ≥ 2.0 virus LRV requirements.
Note 4: Only valid for UVI single setpoint reactor, for UVI variable set point reactors – a flowmeter per reactor is recommended.
Note 5: Master UVT sensor is referred here for a single sensor to be installed in the common header/line.

6. Process Control Requirements

6.1. General Requirements

a. I-SPE-STD-013 Control Systems Design and Construction provides the minimum technical requirements for the procurement, design, installation & construction of control systems inclusive of PLCs, SCADA, communications, and ancillary equipment.

b. Functional Descriptions for UV Disinfection Systems shall be developed to describe process control narrative, process hierarchy, control hierarchy and other control requirements in detail. Functional Descriptions shall use the following standards and templates as necessary:

   i. B-SPE-STD-005: Functional Description Documentation

   ii. I-TMP-STD-001: Functional Description Part A

   iii. I-TMP-STD-005: Functional Description Part B

   iv. I-SPE-STD-013: Control Systems Design and Construction

c. The vendor shall deliver the UV system as a package unit following cyber security and other requirements as specified in this document. Package system controllers are typically changed in / out by Seqwater, see further requirements of equipment specification and maintenance requirement in Section 6.2.1.

6.2. Functional Requirements

a. Each reactor shall have its own locally mounted Local Control Panel (LCP).

b. Each LCP shall enable an operator to toggle equipment between the following equipment modes via a hardwired switch located on the LCP (See Section 6.3 for more detail regarding control modes):

   i. Off

   ii. Local

   iii. Remote

c. The plant main control system shall permit reactors to automatically start-up or shut-down as required by the system demand - based on flow or dose requirements.

d. The start-up sequence for UV reactors should be developed considering the cooling water requirements during start-up starting from cold or warm conditions after a power interruption event. Where incorporated, the start-up sequence may also include the stoppage of recirculation pumps around the UV reactors.

e. Where multiple UV reactors are installed, the start-up sequence of UV reactors shall meet the validated conditions for routine operation.

f. UV reactor and systems shall be automated and control measures suitable to enable continuous operation with the assumption that plants will be unmanned. Manual intervention will be available in the event of system failures; however, it may not be immediate.

g. Operators should be able to vary the flow rate to reactors by manipulation of feed pumps or flow control valves. Gravity should not be relied upon as the sole means of flow control.

h. Operators should be able to control lamp power level and lamp cleaning cycle in manual when required.

i. Upon restoration of the power supply after an interruption, the UV system shall automatically revert to the normal ready state for the next plant run without an operator intervention.

6.2.1. PLC & HMI Functionality

a. UV systems shall be controlled by a dedicated PLC or microprocessor including start up and shut down. However, the plant PLC will initiate UV reactors start-up and shut-down sequence.

b. The layout and functionality of Human and Machine Interface (HMI) screen shall be determined by the UV reactor manufacturer.

c. The UV reactor manufacturer shall require obtaining Seqwater agreement for the communication protocol among UV PLC, plant PLC and SCADA. Communications to the plant PLC should be routed through an approved network segregation device, ensuring a robust firewall that protects Seqwater control systems from cybersecurity threats.

d. The control system and HMI screen equipment shall be as per standard specification of I-LST-STD-001 Control Systems Prescribed Equipment. Where the prescribed equipment requirement cannot be met for the third-party control package, advice from Seqwater must be sought before proceeding.

e. If control equipment is selected outside of the list of I-LSt-STD-001, spare process controllers, that can be readily swapped in / out, shall be provided as part of the project. Seqwater generally does not maintain such control equipment and its configurations, and it shall be agreed and documented as part of the project.

f. Table 7 summarises the minimum signal transfer requirements from the UV system to the SCADA.

6.2.1.1. UV Intensity Set Point Systems

When using the UV Intensity Set Point approach for control, the local HMI shall include a page that allows plant operators to select between different operating setpoints for the UV reactors:

a. The number of selectable setpoints may be specified by the project; or

b. Where not specified by the project, the number of selectable setpoints shall be minimum 4.

6.3. Control Modes

a. UV reactor systems shall support the following equipment control modes:

    i. <u>Local</u> – In Local Mode the UV reactor system is controlled at the LCP.

    ii. <u>Remote Mode</u> – When the locally mounted mode switch is selected to “Remote”, control of the UV reactor system shall be selectable remotely.

b. Remote Mode shall support remote selection of the following group modes:

    i. Remote Manual – operators select which UV reactors operate, and the setpoints at which they operate. In this mode, hardware/hardwired and trip interlocks remain functional.

    ii. Remote Automatic – the Plant PLC determines which UV reactors operate and the setpoints at which they operate. All interlocks (i.e. hardware/hardwired and trip interlocks), process permissive and start permissive remain functional, with the system able to automatically changeover units as required.

c. Switching equipment control modes and group modes of individual reactors shall be available independently of all other installed reactors.

d. Equipment and devices shall be programmed to include Disable and Maintenance Functions as described in I-SPE-STD-013. Instruments shall be programmed to include Instrument Calibration Functions as described in I-SPE-STD-013.

6.4. Start-up and Operation Process Control Narrative

6.4.1. Local Start-up and Operation

a. When a reactor switch is turned to 'Off':

  i. The reactor outlet isolation valve shall close, preventing flow through the reactor.

  ii. The reactor lamps shall switch off.

  iii. If required by the reactor, a lamp cooldown period (interlock on timer) preventing further operation or start-up shall be triggered. The reactor shall be locked out of operation until the pre-programmed timer elapses.

b. When a reactor is switched to 'Local Mode', start-up and operation should use the following logic:

  i. Operation of the UV reactor shall be independent of the Plant PLC.

  ii. Where installed and not already open, the system shall ensure any upstream isolation valve is opened, and the reactor is flooded.

  iii. All UV reactor lamps shall be switched on.

  iv. The system shall allow for a lamp warm-up period in accordance with vendor requirements.

  v. Lamp power level shall be controlled in manual to achieve the required UV intensity. Note that the dose monitoring equation for RED calculation will note be available for this mode.

  vi. Where installed and required, the flow control valves shall be opened in manual at desired opening positions.

  vii. The automatic UV reactor outlet isolation valve shall be opened.

  viii. The plant pumps shall be called to start.

  ix. (UV Intensity Setpoint Approach systems only) Alternatively, the operator may select the desired operating setpoint, and the reactor will adjust its lamp power automatically to meet the setpoint.

  x. The UV reactor will operate using its intended operating approach.

  xi. All hardwired interlocks will remain active in this mode.

6.4.2. Remote Start-up and Operation

a. When switched to 'Remote Mode', operation of the UV reactor shall be determined via selection of the desired group mode remotely:

  i. Remote Manual; or

  ii. Remote Automatic

b. When selected to 'Remote Manual', start-up and operation should use the following logic:

  i. Operator selects preferred reactor to start.

ii. Where installed and not already open, the system shall ensure any upstream isolation valve is opened, and the reactor is flooded (downstream isolation remains in place).[8]

iii. All UV reactor lamps shall be switched on.

iv. The system shall allow for a lamp warm-up period in accordance with vendor requirements.

v. All UV lamps shall ramp to maximum power.

vi. Where installed and required, the flow control valves shall be opened at desired opening positions.

vii. The UV reactor outlet isolation valve shall be opened.

viii. The plant pumps shall be called to start.

ix. The system will regulate based on the dose control approach:

    1. (UV Intensity Setpoint Approach Systems) The UV reactor shall regulate the UV dose by varying the lamp power to one of the pre-defined lamp UV intensity setpoints.

    2. (Dose Approach systems) The UV reactor shall regulate the UV dose by manipulating lamp power output using an algorithm that accounts for flow rate, UV Intensity, UV transmittance, combined age and fouling factor, to achieve the pre-defined operator setpoint.

x. Hardware/hardwired and trip interlocks will remain functional in this mode.

c. When switched to 'Remote Automatic', start-up and operation should use the following logic:

i. The Plant PLC will determine the number of reactors required online based on plant throughput, dose requirements, and duty philosophy for the plant.

ii. Each time the UV system is activated, a duty changeover should occur to minimise the number of starts per day.

iii. Where installed and not already open, the system shall ensure any upstream isolation valve(s) are opened and the reactor(s) are flooded (downstream isolation should remain in place).[8]

iv. All UV reactor lamps for the initiated reactors shall be switched on.

v. The system shall allow for a lamp warm-up period in accordance with vendor requirements.

vi. All UV lamps will ramp to maximum power.

vii. The UV reactor outlet isolation valves will open.

viii. The plant pumps shall be called to start.

    1. The system will regulate the total number of active reactors and individual reactor parameters:

    2. (UV Intensity Setpoint Approach Systems) The UV reactor shall regulate the UV dose by varying the lamp power to one of the pre-defined lamp UV intensity setpoints.

[8] Recirculation or run to waste may be necessary to prevent flow of untreated water.

3. (Dose Approach systems) The UV reactor shall regulate the UV dose by manipulating lamp power output using an algorithm that accounts for flow rate, UV Intensity, UV transmittance, combined age and fouling factor, to achieve the pre-defined operator setpoint.

ix. Where installed, the system will maintain the equal flow through each reactor controlling the flow control valves.

x. The UV system will continue to monitor process plant conditions and regulate the individual reactors and number of reactors online to meet plant demands.

xi. Hardware/hardwired and trip interlocks, process permissive and start permissive will remain active in this mode of operation.

1. When in Remote Automatic Mode, the following functional requirements shall be in place:

2. If all reactors are selected to Automatic Mode, the reactors shall start-up and shutdown in accordance with pre-programmed logic. Reactors will provide the UV dose in accordance with a pre-defined operator setpoint.

3. When a single UV reactor is set to PLC Automatic mode, the single reactor will operate to provide a UV dose in accordance with the pre-defined operator setpoint(s). Other reactors not set to PLC Automatic mode will continue to operate in their selected mode independently.

6.5. UV Reactor Shutdown

The UV reactor(s) will shutdown automatically on generation of a major / critical alarm, or when a plant shutdown is triggered by the control system or operator. The following sequence should be followed:

a. Signal to plant to shutdown.

b. Downstream isolation valve and control valve closes.

c. Reactor de-energises upon valve closing.

d. Timed interlock triggered to prevent further start-up until reactor lamps have cooled.

e. Where incorporated, the reactors should be kept in energised stand-by mode with the recirculation pump running rather than de-energising the reactors when the plant shuts down automatically from the plant PLC.

6.6. Monitoring, Fault and Alarm Management

6.6.1. Package Plant and SCADA Interfacing

a. Designers shall refer to I-SPE-STD-013 Control System Design and Construction for general details on SCADA monitoring and trending requirements.

b. Table 7 provides details of the signals and parameters associated with UV disinfection systems required to interface/output to on-site SCADA. In addition, several other water quality parameters not included in Table 7 may need to be monitored with a defined frequency to evaluate UV reactor performance and minimise operational problems.

Table 7 Summary of UV System Signals (to be fed to SCADA), Monitoring/Trending Requirements.

Signal	Measure	Signals	Comment
Date & Time	dd/mm/yyyy hr:mm:ss		
Instantaneous flow to each UV Reactor (Flowmeter)	L/s	1 signal per reactor	This will be from the UV reactor
Total instantaneous flow to UV disinfection	L/s and ML/d	None (sum of individual flow meters)	
Validation UV Dose[9]	mJ/cm^2	1 signal per reactor	.
Reduction Equivalent Dose (RED) [11]	mJ/cm^2	1 signal per reactor	Where RED is used, must be the most conservative pathogen being targeted (i.e. virus rather than Crypto).
UV Dose Set Point[11]	mJ/cm^2	1 signal per reactor	May be based on validated dose or RED.
Instantaneous UV transmittance (UVT Monitor) [10]	%	1 signal per instrument.	
Instantaneous UV Intensity (UVI Monitor)	mW/cm^2	Minimum one per reactor. For MP systems, one per lamp or averaged UVI.	

[9] Dose Control Approach systems.

[10] Where a UVT sensor is used.

Signal	Measure	Signals	Comment
Average UV intensity used in dose calculation	mW/cm^2	None (calculation)	
Output power percentage for each bank (bank power level) [11]	%	1 signal per bank (minimum 1 per reactor)	
Number of operational banks	Nr.	1 signal per reactor (where relevant)	
Number of operational UV lamps for each bank / number of failed lamps per bank	Nr.	1 signal per reactor	
Number of banks contributing to the dose equation	Nr.	1 signal per reactor	
S/S_0 value (relative lamp output) to monitor fouling/aging factor [12]	%	1 signal per reactor	
Predicted UVI sensor value at the current UVT and ballast power[13]	mW/cm^2	1 signal per reactor	Requires UVT monitoring – optional. May be used for online monitoring of UVI sensors.

[11] Where a UVT sensor is used.

[12] S/S_0 is the ratio of UV intensity of lamps divided by UV intensity of a new lamp (given as %).

[13] May not be available with all systems – only available with UVT monitoring.

Signal	Measure	Signals	Comment
Power Consumption	kW	1 signal per reactor	
Total Power Consumption	kWh	None (Totalised from active reactors)	
Cumulative Power Consumption per Reactor	kWh	None (calculation)	Re-settable
Cumulative Power Consumption of UV Plant	kWh	None (calculation)	Re-settable
Lamp status	On / Off	1 signal per lamp bank (minimum 1 signal per reactor)	Each lamp status should be available at local control panel, but only one signal per lamp bank or reactor can be considered to send to the SCADA
UV Bank Status (individual Banks)	On / Off	1 signal per reactor	
Reactor Start-up Sequence Timer with Lamps Warm-up Period	min	1 signal per reactor	
Reactor Shut-down Sequence Timer	min	1 signal per reactor	
Reactor Running Timer	h	1 signal per reactor	Re-set after each start
Hours Run per Lamp	h	None (calculation)	Re-settable after Maintenance
Hours Run per Bank	h	None (calculation)	Re-settable After Maintenance
Hours Run per Module	h	None (calculation)	Re-settable After Maintenance
Starts per Bank	Nr.	None (calculation)	Re-settable After Maintenance

Signal	Measure	Signals	Comment
Starts per Reactor	Nr.	None (calculation)	Re-settable After Maintenance
Auto Cleaning Status	On / Off	1 signal per reactor	
Intensity Monitor Status	On / Off	1 signal per instrument	
UV Transmittance Monitor Status	On / Off	1 signal per instrument	
Reactor Flowmeter Status	On / Off	1 signal per instrument	
Reactor/Water Temperature	°C	1 signal per instrument	
Ballast Cabinet Temperature	°C	1 signal per ballast	
Reactor Liquid Level Switch	On / Off	1 signal per instrument	

6.6.2. Alarms Management

a. Refer to Seqwater Standard Specifications I-SPE-STD-013 Control System Design and Construction and I-SPE-STD-006 Monitoring and Control System Alarm and Event Management which outlines the philosophy that should be applied to the assessment of alarm priority.

b. An assessment and validation-based approach shall be applied in determining plant alarms. The requirements for critical control points (CCPs) are described in SPE-00320 WTP and Supply System Process Validation Standard and the above referenced documents.

c. Table 8 summarises the typical alarms expected in UV systems. Their suitability and functions shall be reviewed during design.

d. Table 9 and Table 10 provide guidance on the key setpoints required for alarming. These values shall be used as a guide but should be assessed on a project-specific basis and in accordance with manufacturer requirements.

Table 8 Summary of typical alarms to be included in UV disinfection systems.

Device / Parameters	Condition	Action
Reactor Flowmeter	Flowmeter Fault / Power Loss	Trip / Interlock – refer Table 11.
	Low	Alarm only
	Low-Low	Timer or logic to prevent alert on reactor startup / shutdown. If flow not recovered after pre-set time, consider initiating reactor shutdown.
	High	At high level, increase number of online reactors to distribute flow.
	High-High	Trip – refer Table 11.
Instantaneous UV Transmittance	Sensor Fault / Power Loss	Trip / Interlock– refer Table 11.
	Low-Low	Trip / Interlock– refer Table 11.
	Low	Alarm only.
UV Dose (RED and/or Validated Dose)	High	Reduce lamp output if option available
	Low	- Increase lamp output. - Bring online additional reactor. - Changeover to standby unit.
	Low-Low	Trip / Interlock– refer Table 11.
Instantaneous UV Intensity	Sensor Fault / Power Loss	Trip / Interlock– refer Table 11.
	Low	Increase reactor lamp output if allowable.

Device / Parameters	Condition	Action
	Low-Low	Trip / Interlock– refer Table 11.
Average UV Intensity	High	-Reduce lamp output if option available
	Low	- Increase lamp output - Bring online additional reactor - Changeover to standby unit.
	Low-Low	Trip / Interlock– refer Table 11.
Reactor/water Temperature	Sensor Fault / Power Loss	Trip / Interlock– refer Table 11.
	High	Trip / Interlock– refer Table 11.
Reactor Liquid Level Switch	Sensor Fault / Power Loss	Trip / Interlock– refer Table 11.
	Low Liquid Level	Trip / Interlock– refer Table 11.
Isolation Valve	Fail Open / Close	Trip / Interlock– refer Table 11.
Control Valve	Fail Open / Close	Trip / Interlock– refer Table 11.
Lamp Status	Fault	Trip / Interlock– refer Table 11.
Lamp Bank Status	Fault	(See Lamp Status)
Lamp Run Time	High	Signal operator to change lamps.
Ballast Temperature	High	Trip / Interlock– refer Table 11.
Cooling System	Fault / Power Loss	Trip / Interlock– refer Table 11.
Earth Leakage	Fault	Trip / Interlock– refer Table 11.
Auto-Cleaning Status	Fault	Trip / Interlock– refer Table 11.

Table 9 Summary of key alarm criteria for UV Intensity Approach systems

Parameters	Minimum Target (Alarm)	Critical Control point (Plant Shutdown)
Flow Rate	≥ 0.9 x Validated Flow Rate	≥ Validated Flow Rate
UVI	≤1.1 x Validated UVI	≤ Validated UVI
UV Lamp Run Time	≥ 0.9 x Validated EOLL	≥ Validated EOLL
UV Lamp Operation	All lamps must be energized[14]	

[14] If a UV reactor is validated with one lamp out of service, then a single lamp failure should only trigger a minor alarm.

Table 10 Summary of key alarm criteria for Dose Control Approach systems.

Parameters	Minimum Target (Alarm)	Critical Control point (Plant Shutdown)
Flow Rate	≥0.9 x Validated Flow Rate	≥ Validated Flow Rate
UVT	≤1.1 x Validated UVT	≤ Validated UVT
Calculated UV Dose	≤1.1 x Validated Dose	≤ Validated Dose
UV Lamp Run Time	≥ 0.9 x Validated EOLL	≥ Validated EOLL
UV Lamp Operation	All lamps must be energized[15]	

6.6.3. Interlocks and Permissive

All interlocks, start permissives and process permissives shall be defined in the Functional Description, and appropriate CCP protection measures defined in the HACCP Plan.

Refer to *I-SPE-STD-013 Control System Design and Construction* for additional information on the application and structure of interlocks and permissives.

Conditions and failures in each reactor (or interfacing systems) shall trigger appropriate responses in all affected systems including control systems of other plant areas, overarching control systems, and external control systems.

Additional interlocks and permissives should be determined based on chemical, plant and process function and criticality, in accordance with *I-SPE-STD-013* requirements.

Before a system or the plant is tripped as an action, the following should be considered:

- Are there alternate control parameters that can be applied?
- Can the last known operating parameter be held safely?
- Can the plant shut down to a safe state immediately, or is a ramp down necessary?
- Could an alternate design prevent the need for a trip in the first place?
- Are there other safety mechanisms in place that may be preferable to trigger in lieu of a plant trip?

Table 11 summarizes the typical trip and hardware/hardwired interlocks to be considered in Seqwater UV disinfection systems. Start permissives, process permissives, trip interlocks and hardware/hardwired interlocks should be modified in accordance with design requirements, and additional and interlocks should be added as necessary for the specific design.

[15] If a UV reactor is validated with one lamp out of service, then a single lamp failure should only trigger a minor alarm.

Table 11 Summary of typical trip and hardware/hardwired interlocks to be considered into UV disinfection systems.

Device / Instruments	Condition	Action	Trip Interlock	Hardware/Hardwired Interlock
Reactor Flowmeter	Fault	Reactor isolated, shutdown and interlocked. Changeover to standby reactor if in Remote Automatic.	Y	N
	Power Loss		Y	N
	Low-Low Flow	If reactor does not recover from FALL for a pre-set duration, hydraulically isolate and shutdown reactor.	Y	N
	High-High Flow	If reactor measures FAHH, hydraulically isolate and shutdown UV reactor or system depending on operating logic.	Y	N
UVT Sensor	Fault	Reactor shall be hydraulically isolated and shutdown. Changeover to standby reactor if in Remote Automatic.	Y	N
	Power Loss			
	Low-Low UVT	If low-low value exceeded for pre-set time, hydraulically isolate reactor and shutdown.	Y	N
UVT Sensors (Dose Control Mode Only)	Fault	Reactor shall be hydraulically isolated and shutdown.	Y	N
	Power Loss			
	Low-Low UVT	If low-low value exceeded for pre-set time, hydraulically isolate reactor and shutdown.		
UV Intensity Monitor (Instantaneous)	Fault	Reactor shall be hydraulically isolated and shutdown.	Y	N
	Power Loss			

Device / Instruments	Condition	Action	Trip Interlock	Hardware/Hardwired Interlock
	Low-Low UVI	Changeover to standby reactor if in Remote Automatic.		
Average UV Intensity	Low-Low	Reactor shall be hydraulically isolated and shutdown. Changeover to standby reactor if in Remote Automatic.	Y	N
Reactor Temperature Sensor	Fault	Reactor shuts down and hydraulically isolated. Changeover to standby reactor if in Remote Automatic Mode.		Y
	Power Loss			
	High Temperatu re			
Reactor Low Liquid Level Switch	Fault	Reactor should shut down and hydraulic isolated. Changeover to standby reactor if in Remote Automatic Mode		Y
	Power Loss			
	Low liquid level			
Reactor Control Valve (if installed)	Fails to Open	Timer should be implemented to shutdown reactor if it fails to open. Changeover to standby reactor if in Remote Automatic Mode.	Y	N
	Fails to Close	*Design dependent	*	*
Reactor Isolation Valve (Upstream of Reactor – if installed)	Fails to Open	Reactor hydraulically isolated and shutdown. Changeover to standby if in Remote Automatic.	Y	N
	Fails to Close	*Design dependent	*	*

Device / Instruments	Condition	Action	Trip Interlock	Hardware/Hardwired Interlock
Reactor Isolation (Downstream of Reactor)	Fails to Open	Timer should be implemented to shutdown reactor if it fails to open. Changeover to standby reactor if in Remote Automatic Mode.	Y	N
	Fails to Close	If a reactor cannot be isolated, plant trip should occur to prevent untreated water leaving plant. Upstream isolation valve may provide system protection if installed.	Y	N
Ballast Temperature	High Temp.	Reactor hydraulically isolated and shutdown. Changeover to standby reactor if in Remote Automatic Mode.		Y
Cooling System	Fault Power Loss	Reactor hydraulically isolated and shutdown. Changeover to standby reactor if in Remote Automatic.		Y
Earth Leakage	Fault	Affected reactor hydraulically isolated and shutdown. Changeover to standby reactor if in Remote Automatic.		Y

Device / Instruments	Condition	Action	Trip Interlock	Hardware/Hardwired Interlock
Lamp Failure[16]	Fault	Affected reactor hydraulically isolated and shutdown. Changeover to standby reactor if in Remote Automatic.		Y
Sleeve Failure	Fault	Affected reactor hydraulically isolated and shutdown. Changeover to standby reactor if in remote Automatic.		Y
UV Dose (RED and/or Validated Dose)	Low-Low Dose	Affected reactor hydraulically isolated and shutdown. Changeover to standby reactor if in Remote Automatic.	Y	N
Auto-Cleaning	Fault	Hydraulically isolate and shutdown reactor. Changeover to standby reactor if in Remote Automatic Mode.	Y	N

[16] If a UV reactor is validated with one lamp out of service, an alarm can be considered from a single lamp failure instead of the reactor shutdown.

7. Project Considerations

7.1. Vendor Documentation and Training

Vendors shall be required to provide the following:

a. Validation certificate for reactors supplied.

b. Validation reports for reactors supplied. This is required for determining operating envelopes and setpoints, and for future planning and development of individual sites.

c. Operation and Maintenance Manuals.

d. Training in the operation and maintenance of their supplied UV system.

e. Details of cyber security as requested by Seqwater.

7.2. Spares

Guidance on recommended spares to maintain on-site where UV disinfection systems are used is provided in Table 12. These may vary on a site and system-specific basis and should be confirmed in consultation with vendors and based on operational experience and subject to Seqwater approval:

Table 12 Spares List of UV system components

Item	Spares Count
UV LAMPS	25%, minimum 2 lamps
LAMP SLEEVES	10%, minimum 2 sleeves
LAMP CABLES	Minimum 2 units
O-RING SEALS	25%, minimum 2 seals
OMC/OMCC WIPERS	25%, minimum 2 wipers
OMC/OMCC WIPER DRIVE MECHANISMS	2%, minimum of 1 drive
BALLASTS	10%, minimum 2 units
BALLAST COOLING FAN	1 unit
DUTY UVI SENSOR	Minimum 2 units – adjust based on operating experience
REFERENCE UVI SENSOR	Minimum 2 units
ONLINE UVT MONITOR	1 unit (if used in control of reactors)
UV CONTROLLER	1 unit

7.3. Safety Requirements

a. Facilities shall have spill kits available for maintenance activities due to the risk of lamp breakage and mercury contamination.

b. All new, retrofit and replacement UV disinfection installations shall have developed an appropriate management and action plan for lamp breakage and containment / clean-up of mercury as part of the project.

7.4. Testing Requirements

a. All UV systems shall undergo a continuous period of operation testing following installation to demonstrate plant performance. This testing shall as a minimum:

    i. Be undertaken for a minimum of 14 days.

    ii. Successfully demonstrate a minimum of 2 days of continuous, uninterrupted testing, without fault, failure, or alarm.

    iii. Hydraulic testing:

        1. Flow to individual reactors not exceeding maximum allowed.

        2. Flow split between reactors not exceeding design tolerance (nominal ±5% unless specified otherwise).

        3. Pressure drop across the reactors does not exceed design tolerances.

b. Successful demonstration of fail-safes, trips, interlocks, critical control point actions through simulated means.

c. Test and successfully demonstrate the following key reactor parameters:

    i. Successful data logging and trending of all specified parameters.

    ii. UV Transmittance to specification.

    iii. UV Dose applied to specification.

    iv. UV Dose received: Minimum dose received meeting/exceeding the design required dose 100% of the test duration.

    v. Power consumption per reactor at maximum flow rate not exceeding design figure by more than 20%.

    vi. Online cleaning systems (i.e. wiping systems if applicable) operation and control to specification.

    vii. Lamp status successful demonstration, no failures.

    viii. Reactor status successful demonstration, no failures.

    ix. Hours run per reactor, lamp, module etc. – successful continuous logging.

7.5. Storage and Preservation

a. Reactors taken offline for a period of 5 or more days should be fully isolated and drained.

b. If a reactor is taken offline for 28 or more days, the reactor vessel should be cleaned and lamp sleeves inspected and cleaned if necessary prior to restarting.

7.6. Performance Guarantee

The UV reactor should meet the performance requirements as stated in UVDGM and mentioned in this standard for a period identified by the project. The following performance criteria may be included:

a. The performance of duty and reference UV sensors, UVT analyser (if provided) compared to the specification.

b. Disinfection capacity of the reactor under the design feedwater quality conditions.

c. Allowable head loss across the reactor at the design flow rate.

d. Estimated power consumption at the design operating conditions.

e. Equipment sensitives to variations in voltage and current.

f. The performance of automated cleaning system (if provided) under the design feedwater and operating conditions.

8. Definitions

The following definitions (Table 13) apply to this Standard Specification.

Table 13 Definitions

Term	Definitions
Seqwater Approval / Acceptance	Written sign-off gained via the deviation process, as detailed in X-PRO-STD-008 Asset Standards Management and Application.
Calculated Dose	The calculated RED (in mJ/cm^2) is determined using the dose monitoring equation as developed during the validation testing
Contractor	An entity engaged by Seqwater to undertake work in accordance with an agreed contract and defined scope of work.
Manufacturer / Supplier / Vendor / Original Equipment Manufacturer (OEM)	The entity that manufacturers or supplies equipment to meet the specifications of the Contractor.
Owner / Principal / Seqwater	The entity that engages the Contractor to undertake the work and takes custody of the outcome. The Owner may delegate responsibilities to other entities to act on its behalf (e.g. a consultant).
Reactor	A vessel or chamber which typically houses UV lamps, lamp sleeves, UV sensors, sleeve cleaning system and baffles or other hydraulic controls.
Reactor Train	A sequence of one or more reactors in series.
Reduction Equivalent Dose (RED)	The UV dose (in mJ/cm^2) derived from the full-scale reactor testing by measuring the log reduction value of the challenge microorganism and entering into the UV dose-response curve prepared from the collimated beam testing. RED values are always specific to the challenge microorganism and the validation testing conditions used for the full-scale reactor testing.
Required Dose	The UV dose (in mJ/cm^2) needed to achieve for the target log reduction credit as specified in US EPA, 40 CFR 141.720 (d)(1).
REX	Seqwater Electronic Document and Records Management System.
Shall / must	Indicates a mandatory requirement.
Should	Indicates a recommendation.
Ultraviolet Absorbance (UVA)	Some organic and inorganic materials in water are able to absorb (and not re-transmit) UV wavelengths of various frequencies. In this document, UVA refers to the absorbance of wavelengths specifically at 254 nm.
UV Dose	The UV energy per unit area incident on a surface, typically reported in units mW.s/cm^2 or mJ/cm^2. It is a function of the UV intensity (measured in mW/cm^2) and duration (given in seconds) to which a pathogen is exposed.
Ultraviolet Transmittance (UVT)	Defined as the percentage (%) of light passing through the medium (water) after accounting for absorbance and scattering, and standardised over a

Term	Definitions
	specific distance (typically 1 cm). This document assumes a standardised UV wavelength of 254nm is used for this measure.
Validated Dose	The UV dose (in mJ/cm^2) delivered as determined during the validation testing. The validated dose must be greater or equal to the required dose to determine the log reduction value.
Validation Factor	A factor that accounts for the bias and uncertainty associated with the validation testing.

9. Abbreviations

The following abbreviations (Table 14) apply to this Standard Specification.

Table 14 Abbreviations

Abbreviation	Description
ADWG	Australian Drinking Water Guidelines
AM	Asset Management
AOP	Advanced Oxidation Process
CCP	Critical Control Points
CCPP	Calcium Carbonate Precipitation Potential
CFR	Code of Federal Regulations (United States of America)
DBP	Disinfection Byproduct
DNA	Deoxyribonucleic Acid
HAA	Haloacetic Acid
HACCP	Hazard Analysis and Critical Control Points
HMI	Human-Machine Interface
EOLL	End of Lamp Life
HBTM	Health Based Targets Manual (WSAA)
LP	Low-Pressure
LPHO	Low-Pressure High-Output
LRV	Log Reduction Value
OCC	Off-line Chemical Cleaning
OMC	On-line Mechanical Cleaning

Abbreviation	Description
OMCC	On-line Mechanical-Chemical Cleaning
MP	Medium-Pressure
PLC	Programmable Logic Controller
RED	Reduction Equivalent Dose
REF	Reduction Equivalent Fluence (considered interchangeable with RED)
SCADA	Supervisory Control and Data Acquisition
THM	Trihalomethane
US EPA	United States Environmental Protection Agency
UV	Ultraviolet (electromagnetic radiation)
UVA	Ultraviolet Absorbance (not to be confused with UV-A which is a wavelength range of UV light). Refer Table 13 for more information.
UVDGM	Ultraviolet Disinfection Guidance Manual (issued by US EPA)
UVI	Ultraviolet Intensity (measured in mW/cm^2)
UVT	Ultraviolet Transmittance. Refer Table 13 for more information.
WSAA	Water Services Association of Australia

10. Reference Documents

The documents listed in Table 15 and Table 16, and the requirements therein, are relevant to this Standard Specification. In their latest editions, these documents form a part of this Standard Specification. Note that this is not an exhaustive list of documents relevant to the works.

Seqwater undertakes regular updates of its Engineering Standards. Before utilising this document, the complete list of Seqwater Engineering Standards should be reviewed to ensure currency and applicability for the proposed works.

Table 15 Reference Seqwater Documentation

Description	Location
SPE-00346 Engineering Standard B-SPE-STD-003 Commissioning Requirements	REX
SPE-00349 Engineering Standard B-SPE-STD-005 Functional Description Documentation	REX
TEM-00303 Engineering Standard B-TMP-STD-013 UV Disinfection System Datasheet	REX
SPE-00395 Engineering Standard D-SPE-STD-001 Water Supply Network Planning, Design and Construction (Seqwater Supplementary Manual to WSAA, Water Supply Code of Australia WSA03-2011)	REX
SPE-00352 Engineering Standard E-SPE-STD-001 Electrical Design and Construction	REX
SPE-00353 Engineering Standard I-SPE-STD-015 Instrumentation	REX
GDE-00369 Engineering Standard E-GDE-STD-011 Energy Metering and Monitoring Guideline	REX
MAN-00391 Engineering Standard E-MAN- STD-001 Energy Efficiency Manual	REX
SPE-00342 Engineering Standard I-LST-STD-001 Control Systems Prescribed Equipment	REX
SPE-00356 Engineering Standard I-SPE-STD-005 High Priority Alarm & Interlock Management	REX
SPE-00357 Engineering Standard I-SPE-STD-006 Alarm and Event Management	REX
SPE-00361 Engineering Standard I-SPE-STD-013 Control Systems Design and Construction	REX
SPE-00360 Engineering Standard I-SPE-STD-011 Control Systems Testing	REX
SPE-00503 Engineering Standard I-SPE-STD-016 Turbidity Analysers	REX
TEM-00221 Engineering Standard I-TMP-STD-001 Functional Description Template Part A	REX
TEM-00222 Engineering Standard I-TMP-STD-005 Functional Description Part B Template	REX
SPE-00320 WTP and Supply System - Process Validation Standard	REX

Description	Location
SPE-00502 Control Systems Cyber Security Standard	REX
SPE-00367 Engineering Standard M-SPE-STD-001 General Mechanical	REX
SPE-00366 Engineering Standard M-SPE-STD-002 Fixed Platforms, Walkways, Stairways and Ladders	REX
SPE-00323 Engineering Standard M-SPE-STD-003 Valves for Water Applications	REX
SPE-00348 Engineering Standard M-SPE-STD-004 Protective Coatings	REX
SPE-00434 Engineering Standard M-SPE-STD-009 Flow Meters	REX
FRA-00014 Enterprise Risk Management Framework	REX
PRO-02140 Engineering Standard X-PRO-STD-013 Engineering Technical Hazard Study Procedure	REX
PRO-02190 X-PRO-STD-006 Equipment Numbering and Naming Convention Procedure	REX
PRO-02205 Engineering Standard X-PRO-STD-008 Asset Standards Management & Application Procedure	REX
PRO-01617 Engineering Standard X-PRO-STD-009 Engineering Design, Construction, Operation and Maintenance Procedure	REX
TEM-00224 Engineering Standard X-TMP-STD-022 Asset Standards Deviation Request Template	REX
PLN-00452 Corporate Energy Strategy	REX
REG-01074 Engineering Standard X-LST-STD-001 Seqwater Preferred Equipment Register	REX

Table 16 Reference External Standards, Specifications, Codes and Literature

Document Name	Document Title
40 CFR 141.720	Code of Federal Regulations (CFR), Title 40, Part 141, Section 720 - [s.l.] : U.S. Government Publishing House, 2018
AS 1345	Identification of the Contents of Pipes, Conduits and Ducts
AS/NZS 1680 series	Interior and workspace lighting
AS 2312.1	1. Guide to the protection of structural steel against atmospheric corrosion by the use of protective coatings - Paint coatings
AS 2312.2	Guide to the protection of structural steel against atmospheric corrosion by the use of protective coatings – Hot dip galvanizing
AS/NZS 4020	Australian/New Zealand Standard: Testing of products for use in contact with drinking water
ADWG 2011	Australian Drinking Water Guidelines Paper 6 National Water Quality Management Strategy NHMRC 2011

Document Name	Document Title
DVGW	Deutsche Vereinigung des Gas und Wasserfaches (responsible for issuing German DVGW Worksheet W294 guidelines)
E.P. Act	Environmental Protection Act (Qld) 1994
UVDGM	Ultraviolet Disinfection Guidance Manual for the Final Term 2 Enhanced Surface Water Treatment Rule (issued by US EPA, 2006)
DS 110	Water Corporation Design Standard: Ultraviolet Disinfection Systems Version 2, Revision 1, April 2021
WHS Act 2011	Work Health and Safety Act 2011
WSA 03 - 2011	Water Services Association of Australia Water Supply Code of Australia V 3.1
WSA 201-2017	Water Services Association of Australia Manual for Selection and Application of Protective Coatings
WSAA Health Based Target Manual	Water Services Association of Australia Manual for the application of Health-Based Target's for Drinking Water Safety, September 2015.
N/A	Comparison of Private Water Supply and Public Water Supply Ultraviolet (UV) Systems: Final Report, Auth. G. Dillon T. and Hall, D. Shepherd. - Swindon : Water Resource Commission, 2016.
N/A	Guidance on the use of Ultraviolet (UV) Irradiation for the Disinfection of Public Water Supplies [Report] / auth. DWI. - London : Drinking Water Inspectorate, 2016.
N/A	Inactivation credit of UV radiation for viruses, bacteria and protozoan (oo)cysts in water: A review [Journal] / auth. W.A.M. Hijnen E.F. Beerendonk, G.J. Medema. - [s.l.] : Water Research, 2006. - January 2006.
N/A	Optimization of UV Disinfection [Report], Auth H. Wright et. al. USA : Awwa Research Foundation, New York State Energy Research and Development Authority, 2007.
N/A	Tworty's Water Supply 7th Edition [Report] , Auth. M.J. Brandt et. al. K Butterworth-Heinemann, 2017.
N/A	Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse, Third Edition [Book], Auth. NWRI, WRF, 2012.
N/A	Ultraviolet disinfection, WaterVal validation guidance document [Report] / Auth. WaterSecure. - Brisbane : Australian WaterSecure Innovations Ltd, 2017.
N/A	UV Lamp Breakage at Melbourne Water Disinfection plant [Report] / auth. B. Murphy M. Daaboul. - Melbourne, Australia : Melbourne Water, 2015.

11. Changes from previous version

This Standard Specification will be regularly reviewed in accordance with the requirements of the Seqwater Controlled Document Management Procedure. Reviews will include consideration of suggestions for alteration or improvement made in accordance with Seqwater Procedure *X-PRO-STD-004 Development and Review of Asset Standards*. Changes made from the previous version are summarised in Table 17 below.

Table 17 Changes from previous version

Section Number	Change
Various	Reformatted to meet new Seqwater Style Guide requirements. Minor updates to wording to clarify requirements, updates to reference documents, add missing components, incorporate learning from last three years. Clarifications and new learning added in: • General requirements of instrumentation and lighting • Pre-filtration and screening • Chemical pre-treatment and impact of bromide in source water • By products from UV disinfection • Cooling water and recirculation pump • UVT and turbidity sensor requirements • Mercury and lamp breakage management • Interlocks and permissives.

Appendix A Comparison of Mercury Lamp Types

Table A-1 Comparison of Mercury Lamp Types

Parameters	Unit	LP Systems	LPHO Systems	MP Systems
UV Spectrum	nm	Monochromatic ~254	Monochromatic ~254	Polychromatic 200 - 450
Mercury State		Liquid	Solid Amalgam	Liquid
Mercury Vapour Pressure	Pa	~0.93	0.18-0.6	4x104 - 40x106
Operating Temperature	°C	~40	60 - 250	600 - 900
Electrical Input	W/cm	0.5	1.5 - 10	50 - 250
Electrical to germicidal UV conversion efficiency	%	35 - 38	30 - 35	10 – 20
Relative no. of UV lamps		Very High	High - Moderate	Moderate - Low
Typical lamp lifetime	Hours	8,000 – 10,000	8,000 – 12,000	3,000 – 8,000
Fasted Restart Condition		Warm Lamps	Warm Lamps	Cold Lamps
Operation under no Flow Conditions	Hours	3	3	0.15
Advantages		- Better energy efficiency (vs MP lamps) - Less mercury per lamp, and less mercury in vapour phase. - Lower operating temperature (reduced fouling potential) - Longer lamp life (vs MP lamps).		- Greater germicidal output per lamp (Fewer lamps needed). - Smaller Footprint.
Disadvantages		- Lower germicidal output per lamp (more lamps). - Larger footprint (greater number of lamps required).		- Lower energy efficiency. - More mercury per lamp (more mercury in vapour phase as well). - Wavelength spectrum shift with lamp aging.

Some literature suggests lamp lifetimes of 20 – 30% greater than shown here. However, experience has shown that lamp lifetimes are typically less that the upper limits suggested by vendors.

Appendix B Comparison of Ballast Types

Table adapted from (US EPA, 2006)

Table B-1 Comparison of Ballast Types

	Transformer-Based Electromagnetic Ballast	Inductor-Based Magnetic Ballast	Electronic Ballast
ADVANTAGES	Moderate power efficiency. Allows for greater separation between UV reactor and control panel / ballast. Greater resistance to power surges. Lower capital cost. Reduced likelihood of interference with electronic devices. Resistance to higher temperatures.	Provides almost. continuous adjustment of lamp intensity. Allows for greater separation between UV reactor and control panel / ballast. Greater resistance to power surges. Low capital cost.	Greatest power efficiency. Allows continuous power adjustment – potential to adjust to lower power levels (e.g. 30%). Lightweight and smaller size. Improved lamp operating life. Reduces lamp end-darkening effects and sputtering. Low heat generation. Low noise production.
DISADVANTAGES	Typically, discontinuous / step-wise adjustment of lamp intensity (poorer control ability). More electrode sputtering and end darkening than electronic systems.	Lowest power efficiency. More electrode sputtering and end darkening than electronic systems.	Most expensive. Typically, more susceptible to power quality problems or fluctuations (poorer power quality tolerance). Maximum distance between ballast and UV lamps likely to be the shortest of options. Shortest allowable cable length from ballast to reactor.

Appendix C UV Disinfection System Datasheet

Refer to B-TMP-STD-013 (TEM-00303) for the Template of UV Disinfection System Datasheet in XL format.

Table C-1 UV Disinfection System Datasheet

seqwater WATER FOR LIFE	LOCATION: e.g. MT CROSBY EASTBANK WTP SUBLOCATION: e.g. Filter House	CONTRACTOR LOGO
	Equipment Datasheet UV Disinfection System	EQUIPMENT TAG(s):
Rex ID: XXXXX Date Printed: 23-Jul-24	Template may be updated and should be accessed from official location prior to each use. Uncontrolled copy valid only at time of printing.	Revision number: XX

Project Document Number:	M-DSH-???-XXX
Usage:	e.g. Tender Specification / Issued for Construction / As Built
Project Number:	XXXXXXXXX
Project Description:	e.g. New UV Disinfection Installation
Equipment Description:	Ultraviolet Disinfection Reactors

REV	DATE	DESCRIPTION	AUTHOR	APPROVED	DATE	SIGNATURE
		e.g. Issued for Tender / Construction				

Section	No.	Item	Unit	MIN	MED	MAX
BACKGROUND						
IDENTITY	1	Equipment Number(s)	Text			
	2	P&ID Number(s)	Text		B-DWG-XXX-XXX	
	3	Service Description	Text			
	4	Hazardous Area Classification	Text			
	5	Installation Detail	Text		e.g. dwg number	
	6	Line Number and Stream Number	Text			
	7	Reference Specification	Text		Rex & Waternet: SPE-00446 / *B-SPE-STD-010 UV Disinfection Systems*	
ENVIRONMENT	8	Operating Environment	Dropdown		Inland / Coastal / Rural / Urban	
	9	Equipment Location	Dropdown		Inside / Outside	
	10	Special Environmental Hazards	Text			
	11	Criteria:		MIN	MED	MAX
	12	Ambient air temperature - Min / Ave / Max	°C	X	Y	Z
	13	Humidity (relative)	%	X	Y	Z
	14	Humidity (relative)	%	X	Y	Z
PROCESS CONDITIONS						
PROCESS FLUID CHARACTERISTICS	15	Criteria (Note 1)		MIN	MED	MAX
	16	Fluid	Text		per Appendix F of X-PRO-STD-006	
	17	Flow Rate	L/s (or m3/h)	X	Y	Z
	18	Design Operating Pressure	kPag	X	Y	Z
	19	Fluid Temperature	°C	X	Y	Z
	20	UV Transmittance (@254 nm)	%	X	Y	Z
	21	Turbidity	NTU	X	Y	Z
	22	Total Suspended Solids	mg/L	X	Y	Z
	23	Dissolved Organic Carbon	mg/L	X	Y	Z
	24	Hardness	mg $CaCO_3$/L	X	Y	Z
	25	Colour	°H	X	Y	Z
	26	pH		X	Y	Z
	27	Free Cl_2	mg Cl_2 / L	X	Y	Z
	28	Ozone	mg/L	X	Y	Z
	29	Permanganate (if dosed)	mg/L	X	Y	Z
	30	Dissolved Iron	mg/L	X	Y	Z
	31	Total Iron	mg/L	X	Y	Z
	32	Dissolved Manganese	mg/L	X	Y	Z
	33	Total Manganese	mg/L	X	Y	Z
	34	Sulphates	mg/L	X	Y	Z
	35	Chlorides	mg/L	X	Y	Z
	36	<Add / Delete as needed>	TBA	X	Y	Z
	37	<Add / Delete as needed>	TBA	X	Y	Z
PERFORMANCE SPECIFICATION						
	38	Service Life	Years			
	39	- Maximum flow Rate (per reactor)	m^3/h			
	40	- Minimum UVT (@ 254 nm)	%			
	41	End of Lamp Life Factor (EOLL) (Aging Factor)	#		Manufacturer to advise	
	42	Solarisation Factor / Fouling Factor (SF)	#		(maximum of 0.80 may be used, Manufacturer to advise)	
	43	Combined Aging and Fouling Factor (CAF)	#		= EOLL x SF	
	44	Required Log Reduction Value(LRV)	No.	<Select from List>	<Select from List>	
	45	Required Dose	mJ/cm^2		<Select from List>	
	46	Reduction Equivalent Dose (RED)	mJ/cm^2		<Select from List>	
	47	Validated Dose	mJ/cm^2		<Select from List>	
	48	Validation Factor				

DESIGN SPECIFICATION				
	49	Reactor Manufacturer	Text	*VTA*
	50	Reactor Model	Text	*VTA*
	51	Country of manufacture	Text	*VTA*
	52	Reactor Profile	Dropdown	<Select from Dropdown>
	53	Reactor Arrangement	Text	xx Total No. Streams xx No. Reactors per stream
	54	Total No. Reactors	No.	
	55	Redundancy Provided	%	*e.g. 20% of total reactors*
	56	Duty Streams	No.	
	57	Standby / Assist Streams	No.	
	58	Installation Orientation	Text	*i.e. Vertical / Horizontal*
	59	Reactor Protection Class / IP Rating	Text / No.	
	60	**PRESSURE RATING**		
	61	Design Pressure	kPa(g)	
	62	Maximum rate of change of pressure (positive)	kPa/s	
	63	Maximum rate of change of pressure (negative)	kPa/s	
	64	**PROCESS STREAM DESIGN FLOW**		
	65	- Process Stream 1	m^3/h	
	66	- Process Stream 2	m^3/h	
	67	<Add / Delete as needed>	m^3/h	
	68	**REACTOR CONSTRUCTION**		
MATERIALS	69	Reactor / Shell	Text	<Material>
	70	Internal wetted surface	Text	<Material>
	71	Gaskets	Text	<Material>
	72	O-Rings	Text	<Material>
DIMENSIONS / MASS	73	Inlet Size (NB)	mm	
	74	- Flange Type	Text	
	75	Outlet Size (NB)	mm	
	76	- Flange Type	Text	
	77	Reactor Dimensions - L x W x H	mm	L | W | H
	78	Reactor Mass - Empty / Full of water	kg	
	79	**REACTOR PERIPHERALS**		
	80	Downstream Glass/Quartz Trap Required	Yes/No	
	81	Upstream Strainer Required	Yes/No	
	82	Upstream Strainer Material	Text	
	83	Upstream Strainer mesh/hole size	mm	
	84	**HYDRAULICS**		
	85	Design Headloss per reactor - Maximum Flow	kPa	
	86	Design Headloss per reactor - Minimum Flow	kPa	
	87	**LAMPS**		
	88	Manufacturer	Text	
	89	Model / Reference No.	Text	
	90	Lamp Type	Dropdown	<select from list (LP / LPHO / MP)>
	91	Number of Banks per Reactor	No.	
	92	Number of Lamps (Per Reactor / Per Bank)	No.	= Lamps per reactor x no. of reactors
	93	Total Number of Lamps	No.	
	94	Number of Lamps per Ballast	No.	
	95	Number of Sensors (per Bank / per Lamp)	No.	
	96	Lamp Life - Typical / Guaranteed	hrs.	
	97	Lamp Guaranteed Stop / Start Cycles	No.	
	98	Lamp Length	mm	
	99	Required Clearance for Lamp Removal = L x W	mm	L | by | W
	100	Lamp Orientation	Text	
	101	Power per lamp	Watts	
	102	UV-C output at 254 nm	Watts	
	103	**QUARTZ SLEEVES**		
	104	Maximum Sleeve Operating Pressure	kPa	
	105	Minimum Sleeve Operating Pressure	kPa	
	106	Pressure: Allowable Rate of Change (increase/decrease)	kPa/s	
	107	Material	Text	
	108	Guaranteed Sleeve Life	years	
	109	New Sleeve Transmittance	%	
	110	End of Life Sleeve Transmittance	%	
	111	**CLEANING SYSTEM**		
	112	Automatic Sleeve Cleaning Required	Yes / No	
	113	Sleeve Cleaning Mechanism Type	Text	e.g. Mechanical Wiper (details of brush etc).

	114	**BALLASTS**						
	115	Ballast Type	Dropdown	<Select from List>				
	116	Manufacturer	Text					
	117	Model / Reference No.	Text					
	118	Guaranteed Ballast Life	years					
	119	Ballast Dimensions: L x W x H	mm	L	by	W	by	H
	120	Cabinet Dimensions: L x W x H	mm	L	by	W	by	H
	121	Weight	kg					
	122	Ballast Cooling Method	Text					
	123	Maximum Heat Dissipation	kW/s					
	124	No. Lamps / Ballast	No.					
	125	Total No. Ballasts / reactor	No.					
	126	Total No. Ballasts	No.					
	127	Power	Watts					
	128	Current	Amps					
	129	Voltage	Volts					
	130	Phases	No.					
	131	Frequency	Hz					
	132	**CONTROL**						
	133	Control Mode:	Dropdown	<Select from List>				
	134	Calculated Dose	mJ/cm^2					
For UVI Set Point	135	Dose Setpoint 1	mJ/cm^2					
	136	Dose Setpoint 2	mJ/cm^2					
	137	Dose Setpoint 3	mJ/cm^2					
	138	Dose Setpoint 4	mJ/cm^2					
	139	Lamp Warm up Period for Start-up	min					
	140	Type of Control System	Dropdown	<Select from List>				
	141	Upstream Isolation Valve per Reactor?	Yes/No					
	142	**INSTRUMENTS**						
	143	Control Panel / Electrical Cabinet	Text	Refer Separate Datasheet				
UVI	144	UV Intensity Sensor(s)	Text	Make / Model				
	145	UV Intensity Sensor(s) Datasheet	Text	Refer Separate Datasheet				
	146	UV Intensity Sensor(s) Datasheet	Dropdown					
	147	No. of UVI Sensors per Reactor	No.					
UVT	148	UV Transmittance Sensor(s)	Text	f				
	149	UV Transmittance Sensor(s) Datasheet	Text	Refer Separate Datasheet				
	150	No. of UVT Sensors per Reactor	No.					
	151	Design UVT	%					
	152	Minimum UVT	%					
Flowmeter	153	Flowmeter Arrangement:	Dropdown	<Select from list>				
	154	Total No. Flowmeters	No.					
	155	Flowmeter Datasheet	Text	Refer Separate Datasheet				
Power	156	**POWER SUPPLIES**						
	157	Power Supply	V/Hz					
	158	Control Voltage (Note 2)	V					
	159	Min Power Modulation or Turndown	%					
	160	Specify Power Quality and Back-up Devices	Text	<enter details of device. E.g. UPS>				
	161	Reference Device Datasheet	Text	<input datasheet document number>				
	162	**POWER**						
	163	Power per Lamp	Watts	<No>				
	164				No. of Lamps On-	Total Power Usage (kW)	Ballast Operating %	
	165	Power Assessment 1 to be specified at: (Note 3)	-	@25% Flow				
	166		-	@50% Flow				
	167		-	@75% Flow				
	168		-	@100% Flow				
	169							
	170	Power Assessment 2 to be specified at: (Note 3, 4)	-	@25% Flow				
	171		-	@50% Flow				
	172		-	@75% Flow				
	173		-	@100% Flow				
	174							
VALIDATION								
TESTING AND CERTIFICATION (SUPPLIER TO PROVIDE DOCUMENTATION)	175	All Materials AS 4020 Certified	Yes/No	Yes / No (- Vendor to provide reports if necessary)				
	176	Validation Protocol Requested	Text	(e.g. US EPA UVDGM)				
	177	3rd Party Responsible for Validation	Text	<enter name>				
	178	Validation Laboratory	Text					
	179	Validation Standard	Text	(e.g. US EPA, 40 CFR 141.720 (d)(2))				
	180	Pre-Validated System Used?	Yes/No					
	181	On-Site Validation Required?	Yes/No	if yes, details to be provided				
	182	Factory Acceptance Testing Witness Required	Yes/No					
	183	Operator Training Required	Yes/No	If yes, details to be provided				
NOTES								
NOTES	184	Note 1: Default specified min / max as 5%ile and 95%ile or as requested by vendor/ supplier.						
	185	Note 2: Different voltage requirement for various components to be specified.						
	186	Note 3: Power assessment to be specified considering design UVT, end of lamp life, design fouling factor and design dose.						
	187	Note 4: Consider additional power assessment at an alternate UVT other than the design UVT.						
	188							
	189							

Appendix D Typical Flow / Instrumentation Arrangements

The following diagrams show typical arrangements for setpoint approach and dose control approach systems. A turbidity monitor has not been included in the arrangement; however, these will be installed upstream of reactors and provide a signal to SCADA rather than the UV control panel.

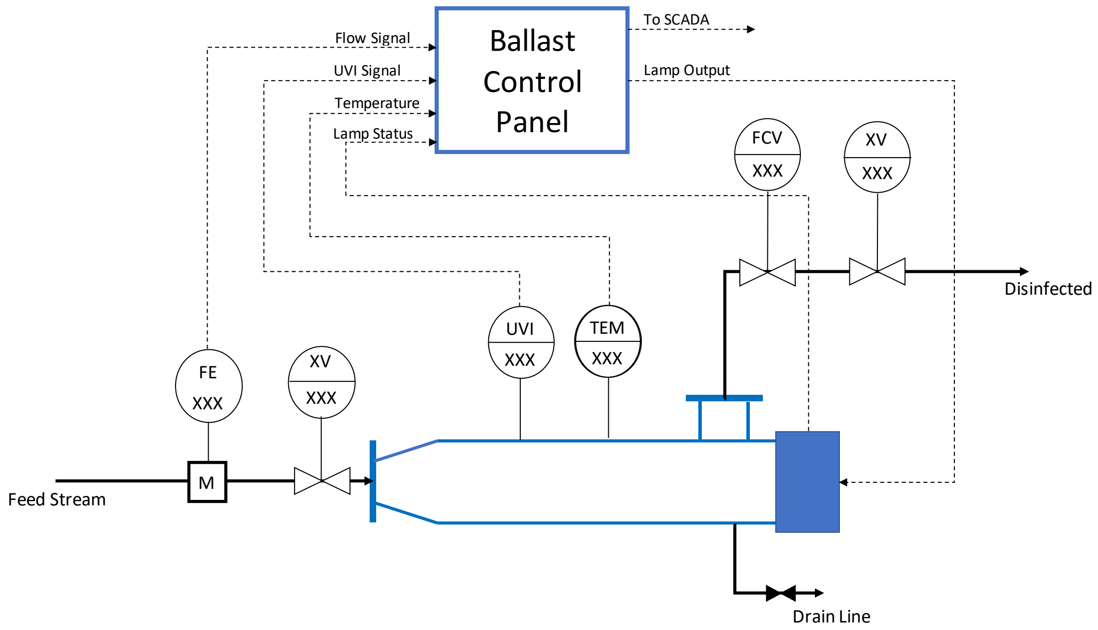

Figure 3 Typical Arrangement of a UVI Set Point System.

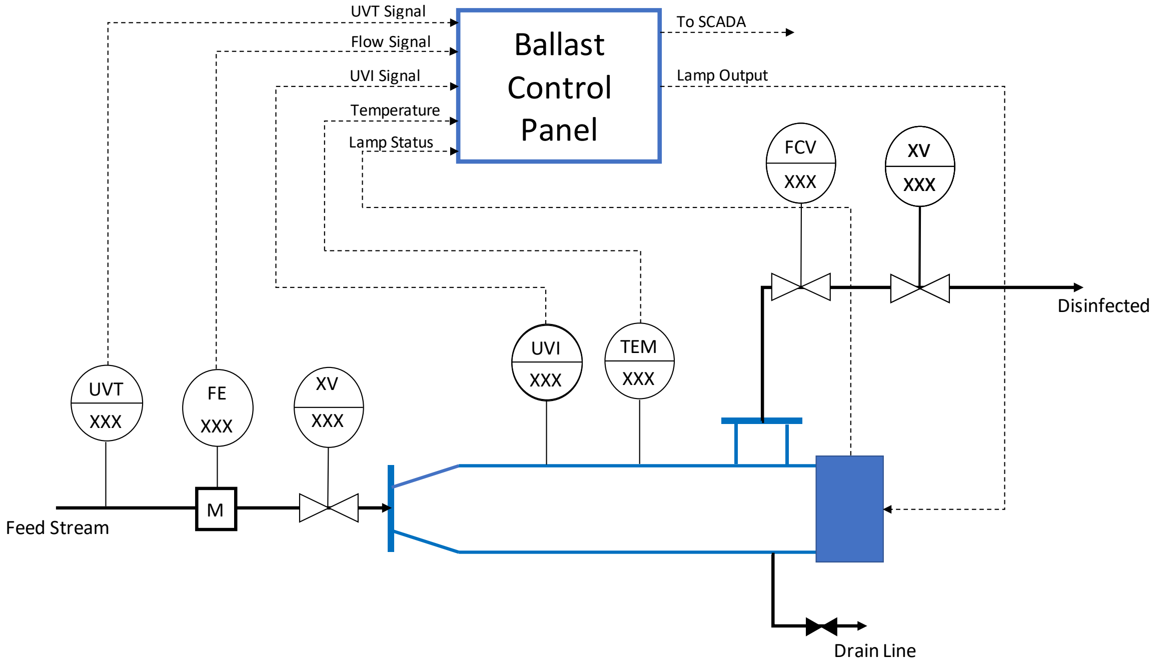

Figure 4 Typical arrangement of a Calculated Dose System.

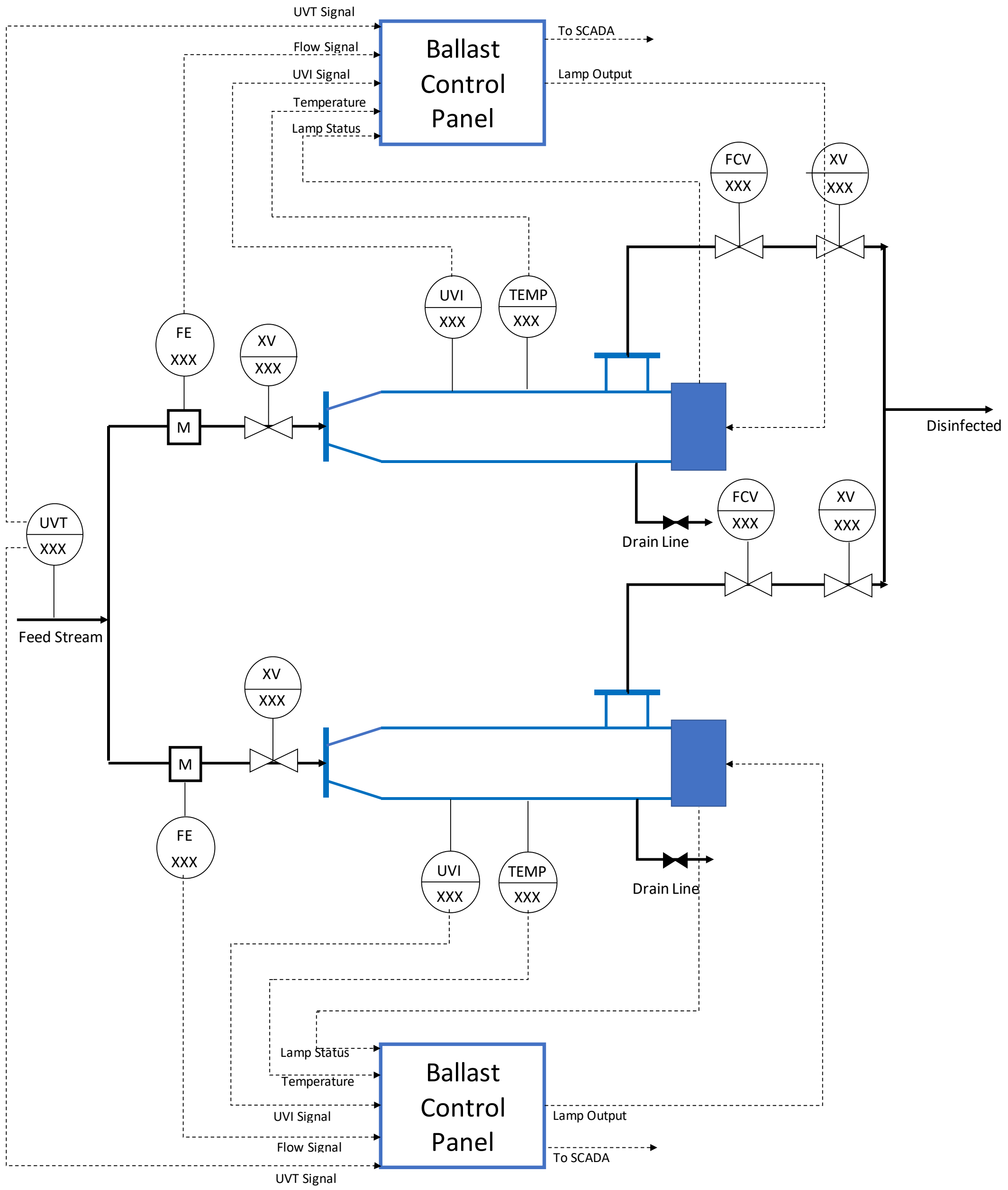

Figure 5 Typical arrangement of multiple reactors in parallel using Calculated Dose approach.